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NOTICES

Disclaimers

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14. ABSTRACT

Dismounted Soldiers consistently experience heavy cognitive and visual workloads during navigation and patrol, particularly under conditions of high stress and time pressure. As a result, a variety of naturalistic user-technology interfaces have been developed to lower workload and enhance dismounted Soldier performance. A series of experiments showed that tactile augmentation to navigation and communication systems can lower workload and enhance performance. This report describes further development of a tactile system that enables simultaneous presentations of navigation and robot communication/monitoring information using tactile patterns composed of 2 types of advanced tactors. Data were collected on 36 Soldiers who volunteered to perform night operations involving waypoint navigation and receipt of incoming messages. They used a standard chest-mounted smartphone visual display, consistent with NettWarrior concepts, integrated with the tactile belt system. Soldiers performed navigation and communication tasks, once with the tactile system turned on and once with the tactile system turned off. Results showed that missions performed with the tactile system turned on were associated with reduced mission times, increased navigation accuracy, very low rates of checking the visual display, and lower reported experience of cognitive workload, effort, and frustration. When using the tactile system, Soldiers reported being more situationally aware of their surroundings and having better control of their weapon.

15. SUBJECT TERMS

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1. Introduction

1.1 Background: Soldier Visual and Cognitive Workload

It has been established that dismounted Soldiers consistently experience heavy cognitive and visual workloads, particularly during navigation and patrol, during ground robot control, and under conditions of high stress and time pressure (Mitchell et al. 2005; Mitchell 2009; Mitchell and Brennan 2009a, 2009b; Pomranky and Wojciechowski 2007). These studies quantify the workload that is familiar to all dismounted Soldiers, particularly when navigating unfamiliar terrain during night operations, when attention demands are high, visibility is low, and the need for stealth is critical.

At the same time, the Soldier must master new technology in the form of displays (e.g., smartphone and tablet map displays), controls (e.g., robot controls), and communication devices. As an example of future trends, a review of emerging technologies assessed for infantry Soldier combat teams during the Army Expeditionary Warrior Experiment included aerial and ground vehicles with sensor arrays, small stationary sensors, more-robust communication capabilities, and improved visual capabilities encompassing weapon sights, binoculars, night vision, and targeting aids (US Army Experimental Center 2013).

Given the high attentional demands, coupled with additional technology that must be mastered, we see clearly that cognitive demands on dismounted Soldiers are increasing, though they are already very high. While these advanced technology devices are meant to assist the Soldier, care must be taken not to further overload him/her with additional demands or distracters. As a result, research has been focused on the development of more naturalistic interfaces that are easy to learn and easy to use, that Soldiers can intuitively understand, that will allow them hands-free operation, and that will free their attention to their surroundings and potential threats.

1.2 Tactile Display Technology

Given the high demands for visual attention, consideration turned toward offloading attentional demands to other sensory channels, as this has been demonstrated to ease workload (Wickens 2002, 2008). While there has been much success in offloading visual tasks to the auditory channel, the effectiveness of this strategy is not as appropriate for the dismounted Soldier due to regular demands for stealth and high background noise during combat operations. Tactile displays presented an opportunity to provide direction and alerting cues that are both intuitive and covert (Self et al. 2008).

Meta-analyses of published experiments meeting criteria for performance-based analyses showed that tactile displays augmented performance when added to visual displays, particularly under conditions of high workload (Elliott et al. 2009). Several experiments were conducted, with the result that torso-mounted tactile displays have proven effective for navigation and communication in field experiments and were very highly regarded by experienced Soldier valuators (Elliott et al. 2009, 2010, 2011). These displays, when integrated with GPS, enabled Soldiers to navigate at night, hands-free (allowing the Soldier to hold his/ her weapon), and eyes-free (allowing focused attention to surroundings as opposed to a display). Torso-mounted displays have also proven effective for Soldier communications and, in fact, proved better than arm and hand signals for critical communications, even during strenuous combat movements (Pettitt et al. 2006). Tactile communications have the advantage during night operations, particularly when the operations require covert communications. They have also been demonstrated as effective for US Air Force Battlefield Airmen (Calvo et al. 2013).

1.3 Research Objectives

This experiment-based evaluation will investigate the efficacy of emerging technology that uses advanced tactile display features to provide both navigation (direction) information and incoming alerts in a manner that should be easily perceived, distinguished, and accurately/rapidly interpreted. The objective of this experiment was to empirically evaluate simultaneous presentations of navigation and robot communication/monitoring using tactile patterns composed of 2 different types of advanced tactors during operationally relevant scenarios. This dual-row tactile cueing approach has been successfully demonstrated and was associated with positive regard by Soldiers (Elliott et al. 2013). As shown in Fig. 1, the concept of tactile cueing during land navigation is that of hands-free, eyes-free, and mind-free performance. The ability to keep hands on the weapon and eyes straight ahead instead of a on a compass or GPS is very important for situation awareness and Soldier survivability while freeing Soldier attention away from effortful tracking of pace counts and consultations with visual map displays.

Fig. 1 Tactile hands-, eyes-, and mind-free navigation

2. Instrumentation

2.1 Tactile NavCom System

Figure 2 shows a block diagram overview of the Engineering Acoustics, Inc. (EAI) NavCom system. The NavCom Soldier hardware comprises a smartphone with integral visual display and touchscreen interface running the NavCom User application. The smartphone connects to an EAI dual-row tactile belt array and a commercial-off-the-shelf GPS/inertial measurement unit (IMU) using USB. A separate, remotely networked computer (laptop) running the NavCom Manager is used for mission planning, task management, and real-time mission analysis.

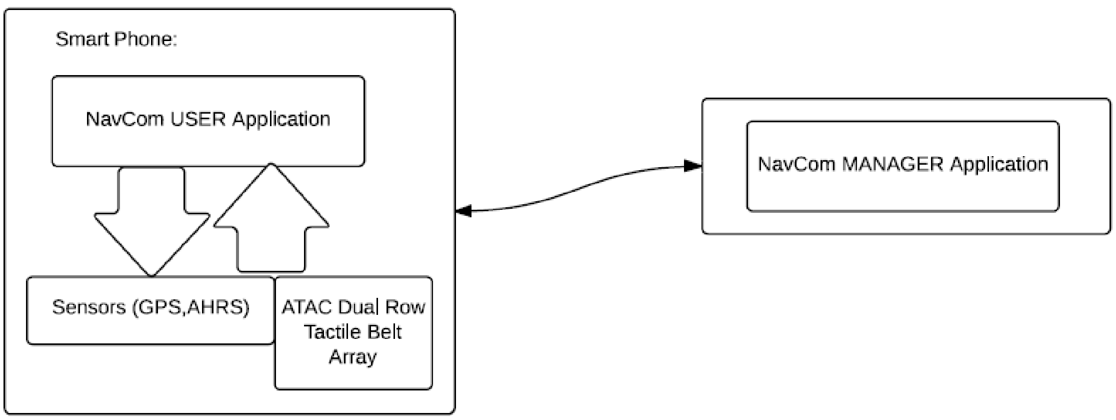


Fig. 2 Block diagram for the Active Tactile Array Cueing NavCom system

Further detail of the NavCom software structure is provided in Fig. 3. The NavCom application program interface can also communicate with standard GPS sensors and is potentially compatible with third-party mapping technologies. An optional secure communication layer can be used for communication to other users.

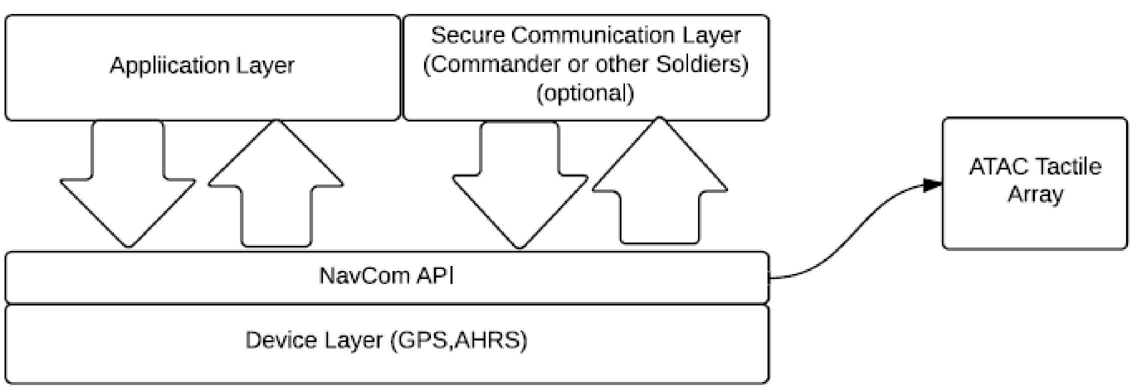


Fig. 3 The NavCom software structure

The NavCom prototype system consisting of a dual-row belt, USB hub, GPS/IMU sensor and Samsung S3 smartphone is shown in Fig. 4. The USB hub and sensors (collectively named the NavCom controller) were integrated within a small aluminum enclosure. The tactor belt consists of 2 rows of 8 C-3 and 8 EMR tactors, contains the tactor controller electronics, and is connected to the NavCom controller with a detachable connector and smartphone.

Fig. 4 Prototype NavCom dual-row tactor belt worn on torso

For the experiments described in this report, the NavCom components were integrated into a Modular Lightweight Load-carrying Equipment (MOLLE) vest shown in Fig. 5. The NavCom controller and a small 2,600-mAH rechargeable battery were mounted in the back pocket of the MOLLE vest. A GPS antenna was mounted on the left shoulder of the vest and the dual-row tactor belt is worn under the MOLLE vest. The smartphone was mounted into a flip-down enclosure containing a USB cable (connected to the NavCom controller).

Fig. 5 Experimental NavCom system mounted in a MOLLE vest

This experiment used commercially available tactors that are relatively small, light, salient, sturdy, bio-isolated, and available from EAI (Redden et al. 2006). Figure 6 shows the EAI C-2 tactor that has proven effective in previous experiments along with the newer and smaller C-3 tactor and a low-frequency-motor-based tactor, the EMR tactor. The C-2 and C-3 are almost equivalent in vibratory output and believed to be equivalent in sensation. The C-3 (6 g) is substantially lighter than the C-2 (18 g). In this evaluation, the C-3 tactor was used.

Fig. 6 The EAI EMR, C-2, and, C-3 tactor transducers (left to right)

Our experimental design required simultaneous presentations of navigation and robot communication/monitoring cues. The EAI dual-row tactor belt potentially allows for the presentation of multiple types of tactile symbology, as the tactor belt is composed of C-3 and EMR tactors. The EMR tactors, based on a rotating mass motor in a proprietary suspension, can produce lower-frequency stimuli, creating sensations that are typically perceived as less “sharp” than the C-3. The C-series tactors are moving magnet linear motor designs optimized for use in the 200- to 300-Hz band. The rise time of the C-3 is less than 2 ms while the EMR rise time is about 12 ms.

In this experiment, the EMR tactor was used for navigation signals. For incoming alerts, C-3 tactors were used, programmed at the frequency that is optimal for human perception (250 Hz). The C-3 produces a highly salient, “sharp” sensation. Both types of tactors create a strong localized sensation on the body by using a moving contactor located within the tactor housing that works like a plunger. The contactor is thus in contact with a known volume of the skin or body load that is the predominant load. The contactor drives the skin with primarily perpendicular sinusoidal movement independent of the loading on the housing, and the housing outer ring acts to damp out any surface vibrations. This design configuration is illustrated in Fig. 7.

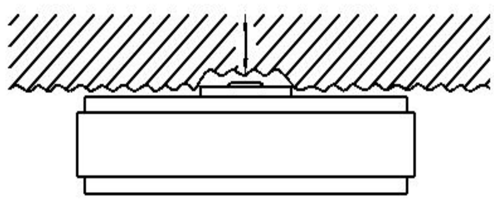


Fig. 7 C-series linear actuator design: front view showing the center contactor (left) and operational schematic (right) showing the contactor acting against the skin load and the housing in simultaneous contact with the load

Table 1 provides a description of characteristics of each type of tactor.

Table 1 Characteristics of C2, C-3, and EMR tactors

Characteristic	C-2 and C-3 Tactors		EMR Tactors
Mechanism	Moving magnet linear actuator		Motor-based actuator
Diameter	C-2: 1.17 inch	C-3: 0.74 inch	1.00 inch
Thickness	C-2: 0.30 inch	C-3: 0.24 inch	0.4 inch
Main frequency	200–300 Hz (but can operate at lower frequencies)		50–140 Hz
Peak displacement	0.016 inch		0.04 inch
Material	Anodized aluminum, polyurethane		Polycarbonate and ABS plastic

Note: ABS = acrylonitrile butadiene styrene.

The combination of an EMR and C-3 in a dual-row belt is shown in Fig. 8.

Fig. 8 EMR and C-3 tactors within a prototype dual-row belt

2.2 Dual-Row Belt Design and Usage

The EAI dual-row belt consists of 2 rows of 8 C-3 and 8 EMR tactors (16 total) with their integrated controllers (EAI 8-channel node controllers internal to the belt). The experimental condition replicated the task demands of the combined direction and robot alert cues while the Soldier was on the move. The dual-belt design allows navigation commands to be presented on one row (and tactor type) while high-priority command information can be given on another row.

The simplest informational requirements for Soldiers completing a navigation task are the direction to a waypoint and notification upon reaching it. This information can be presented to them on a torso-worn tactor array. Directional information is naturally mapped to corresponding sectors on the torso, and studies (Cholewiak et al. 2004) have shown that an array of 8 tactors in a single row around the body is sufficient for accurate navigation (e.g., more tactors would not result in higher precision). Practical tactile and multisensory display systems should be designed for salience (i.e., rapid and easy comprehension). Thus, conveying simultaneous tactile direction and command cues can be challenging as the tactile technology, human perception limits, and task environment may impose real practical limits on the salience of tactile cues and the effectiveness of users in detecting and identifying relevant patterns (Elliott et al. 2013).

Based on previous experiment results (Redden et al. 2006), single-heading cue locations were designated by 8 cardinal directions, as shown in Fig. 9. Tactor 1 corresponds to the front and tactor 5 corresponds to the back for the bottom row of EMR tactors. Tactor 9 corresponds to the front and tactor 13 corresponds to the back for the top row of C-3 tactors. Navigation information was provided based on the Soldiers' orientation and position with respect to a predetermined navigation task. Heading is presented in local coordinates (i.e., relative to Soldier heading), thus no interpretation or spatial translation is needed.

Fig. 9 Placement of tactors

The navigation information was provided to the Soldier during navigation legs by providing a pulse pattern on the tactor sector corresponding to the direction toward the next waypoint. As the Soldier moves closer to the waypoint, the tactor pulse repetition rate increases until the waypoint is reached, upon which the Soldier is notified with a tactor message pattern. Similarly, additional navigation message cues such as warnings associated with keep-out zones can also be designed.

Tactile patterns have been developed and validated using Soldiers in static postures and dynamic movements (Gilson et al. 2007). These patterns were intended to be salient (e.g., easy to perceive and interpret). For example, the tactile pattern for "rally" has tactors sequentially activated around the waist, creating a feeling of movement that is easily distinguished and consistent with the Army hand and arm signal for rally (i.e., hand up and moving in circular motion).

Navigation cues primarily used the following EMR tactors:

- Direction: EMR row
- Distance: EMR pulse rate (pulse repetition rate 0.1–5.0 Hz)
- Waypoint Reached: Rally C-3 row
- Exclusion Zone: Halt C-3/EMR

Similarly, tactile pattern command cues have been developed for incoming robot communications using the C-3 tactors.

2.3 Tactile Messaging

Robot commands were presented on the C-3 row, as follows:

1. Wheels Spinning: Participant must alert robot operator to ensure robot does not remain nonmission capable.
2. Battery Low: Participant must ensure robot operator does not become nonmission-capable.
3. Possible Target Ahead: Participant would have to alert his/her squad or risk operational forces engagement.
4. Nuclear, biological, chemical (NBC) Detected: Participant would have to don his/her protective mask and alert squad to do the same.

Cues were only given once per presentation. Details of the cues used can be found in Appendix A.

2.4 Hardware Used in the Experiment

This experiment occurred at night; therefore, Soldiers were provided with night vision capability. Soldiers used a standard military monocular night vision system. The PVS-14 Alpha (Fig. 10) is currently used by the US armed forces and special operations units. The PVS-14A includes a built-in infrared illuminator, fully adjustable head mount, and military-specification multicoated optics. Automatic brightness control and bright source protection are standard. The manual gain control feature allows the user to increase or decrease image tube brightness for best possible image contrast in high- and low-light conditions. The PVS-14 Alpha can be used hands-free, weapons-mounted, or attached to a camera or camcorder for nighttime photography.

Fig. 10 PVS-14 Alpha

Figure 11 shows a Soldier wearing the complete NavCom Soldier System used in the experiments.

Fig. 11 Soldier using the prototype NavCom Soldier system

EAI provided the computers, smartphones, and GPS sensors for testing. At least 2 simultaneous NavCom system test configurations were available with sufficient spare components, and various dual-row tactor belt sizes were available. Each NavCom system was paired with a Samsung Tab 3 tablet that was carried by the data collector. The tablet was used by the data collector to manage the experiment (according to the following experiment protocol) and record any of the Soldiers' responses to cues.

3. Experimental Method

3.1 Participants

The 36 Soldier volunteers who participated in this data collection were recruited from active-duty units at Fort Benning, GA: 34 males and 2 females, ranging in age from 18 to 31 yr (mean = 23), ranging in height from 60 to 74 inches (mean = 70), and weighing from 123 to 240 lb (mean = 175). Very few reported being ticklish in the chest/waist area (mean = 1.94, where 1 = not at all ticklish and 5 = very ticklish). They averaged 31 months of military service, and ranged from PVT to SGT. Their occupational specialties were predominantly infantry/armor and support operations. Twelve Soldiers listed deployments in combat operations such as Iraq and Afghanistan.

3.2. Procedures

Each Soldier participant was briefed on the purpose of the investigation, the procedures to be followed during the experiment, and any risks involved in their participation. Risks were described in the informed consent form, which was presented to all participants (see Appendix B). The investigator communicated the experiment goals, procedures, risks, and issues explicated in the consent form. Soldiers were given an opportunity to review the experiment objectives, have any of their questions answered by the investigators, and asked to sign the consent form indicating their informed voluntary consent to participate. The participants were informed that if they chose not to participate, they could convey that choice privately to the experimenter. If the participant agreed to take part in the investigation, he/she completed the information on the last page of the affidavit and signed it. The form also requested their permission to have photos or video taken, which participants could decline.

A demographic questionnaire was administered to the participant to obtain pertinent information on his/her background (see Appendix C). Each participant was assigned a roster number for data collection purposes. The roster number was used on all questionnaires including the demographic questionnaire to ensure privacy, in lieu of names or other personal identifying information. The roster number was only associated with the participant name on the informed consent document. The informed consent documents are secured in a locked file cabinet. Data obtained during the training and testing periods are stored separate from documents containing personal information. All data and information obtained is considered privileged and held in confidence. Any photographic or video images taken of the participants during the experiment was not identified with any of their personal information (name, rank, or status). Additionally, we asked the participants to remove their name badge and we pixilated the image to obscure their face.

In pre-experiment training, participants donned the tactile belt while an experimenter fit the tactile belt ensuring the fit was above the waist below the sternum. Participants were then trained on the tactile patterns. Participants were given a visual poster of a representation of the tactile patterns and received a brief explanation of each pattern. Participants were first provided each pattern several times to allow them to become familiar with how each tactile pattern felt. Next, the tactile patterns were provided in a random order, and the participants were asked to verbalize which pattern they received. The investigator informed participants if they made any identification errors. Sound masking was then introduced, the visual representation removed, and the training continued. The training was completed once the participants could correctly identify all of the randomized patterns correctly twice in a row. The initial orientation and training is shown in Fig. 12.

Fig. 12 Classroom training

3.3 Experiment Design

3.3.1 Scenario and Task Demands

There were 2 similarly designed courses in an effort to minimize the learning effect. There were 3 legs per course approximately 300 m in length (900 m per course). Each leg was negotiated as follows:

- Leg 1. Navigation with alerts: The Soldier started at a designated start point and used equipment (baseline or tactile system) to navigate to waypoint 1 as accurate tactically as possible. This leg included 12 alerts from the robot with which the Soldier acknowledged and responded verbally.
- Leg 2. Navigation with exclusion zone: The second leg was similar to leg 1, with the addition of an exclusion area that the Soldier had to avoid. The robot alerts were not given during this leg. The exclusion zone was a circle with a radius of at least 20 m and it crossed the direct route from waypoint 1 to waypoint 2 and was marked as such.
- Leg 3. Navigation with alerts and target detection: The Soldier then navigated from waypoint 2 to waypoint 3. This leg included the 12 alerts from the robot with which the Soldier acknowledged and responded verbally. During this leg, the Soldier was requested to find as many targets as possible. There were 20 targets (e.g., silhouette targets) situated throughout this leg. Placement of the targets was systematically equated for the 2 routes. There were an equal number of targets that were close, mid-range, and far off the path.

One course (3 waypoints) was estimated to take about 45 min or less to complete. The various legs of the course are depicted in Fig. 13. To fit in 2 equivalent courses (without any common areas), the experimental course was designed to have multiple interim waypoints in each leg as shown in Figs. 14 and 15. Course participants are shown in Fig. 16.

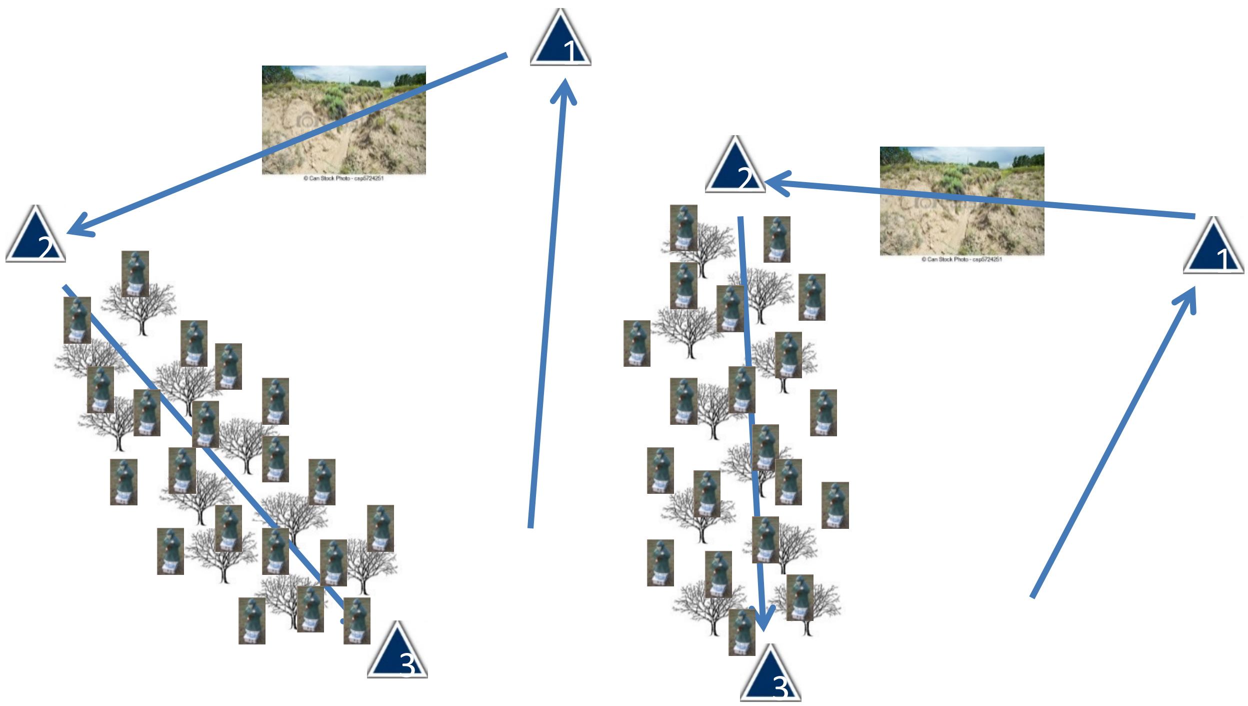


Fig. 13 Layout of 2 equivalent navigation routes with 3 waypoints, exclusion zones, and targets

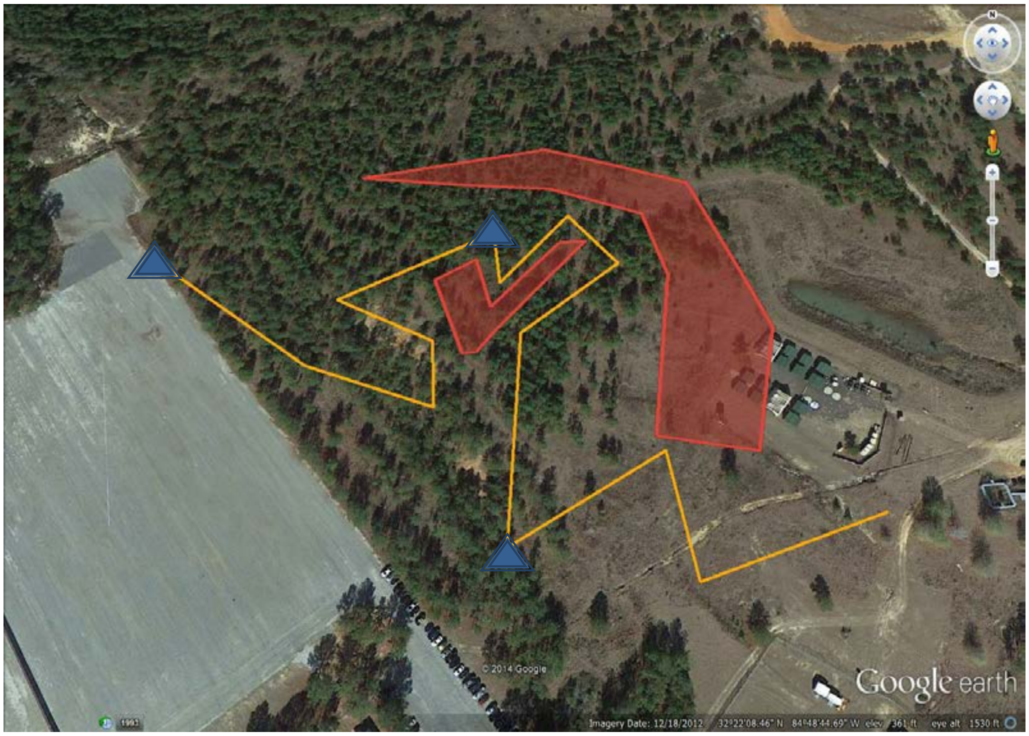


Fig. 14 Course A showing waypoints (triangles) and exclusion zones (shaded)

Fig. 15 Course B showing waypoints (triangles) and exclusion zones (shaded)

Fig. 16 Two Soldier participants and a data collector

3.3.2 Assignment to Experiment Conditions

Soldiers were assigned to experiment conditions as shown in Table 2. This ensured a counterbalanced order of presentation.

Table 2 Assignment of roster numbers to experiment conditions

Roster	Route (A or B) Condition (Tactile On/Off)	
1, 5	A Off	B On
2, 8	B Off	A On
3, 7	A On	B Off
4, 6 … etc.	B On	A Off

Two different schedules were required for complete counterbalancing of conditions. Tables 3 and 4 provide an overview schedule for data collection for days 1 and 2. These schedules lay out the conditions and feedback (FB) times (A base, A belt, B base, and B belt and the survey completion [FB]). These 2 schedules were used on subsequent days (e.g., day 1 schedule used for odd number days, and day 2 schedule was used for even numbered days).

Table 3 Overview schedule for day 1 and all odd-numbered days

	Roster					
Time	**1**	**2**	**3**	**4**	**5**	**6**
2000–2100	A base	…	…	B belt	…	…
2100–2200	FB	B base	A belt	FB	…	…
2200–2300	…	FB	FB	…	A base	B belt
2300–2400	…	…	…	…	FB	FB
2400–0100	B belt	…	…	A base	…	…
0100–0200	FB	A belt	B base	…	…	…
0200–0300	…	FB	FB	…	B belt	A base
0300–0400	…	…	…	…	FB	FB

Table 4 Overview schedule for day 2 and all even-numbered days

Time	Roster 7	Roster 8	Roster 9	Roster 10	Roster 11	Roster 12
2000–2100	…	…	A base	…	…	B belt
2100–2200	…	…	FB	B base	A belt	FB
2200–2300	A belt	B base	…	FB	FB	…
2300–2400	FB	FB	…	…	…	…
2400–0100	…	…	B belt	…	…	A base
0100–0200	…	…	FB	A belt	B base	FB
0200–0300	B base	A belt	…	FB	FB	…
0300–0400	FB	FB	…	…	…	…

Each Soldier spent about 30 min after each run filling out forms and providing feedback.

3.4 Measures

3.4.1 Performance-Based Measures

Experiment measures included subjective and performance-based measures, the latter including the following:

- Time: The data collector used the NavCom tablet to log times, resulting in times (minutes, seconds) for each navigation leg and an overall time.
- Incoming alerts: The data collector initiated messages to the Soldier and indicated on the NavCom system whether the Soldier interpreted the message correctly. The NavCom system logged the time and the accuracy of the alerts.

- Waypoint completion: The data collector noted whether the Soldier arrived at each waypoint. The route of each Soldier was also logged by the NavCom system. If the Soldier was unable to find the next waypoint within 20 min, the data collector made note of it, recorded the time, and guided them to the next waypoint.
- Exclusion area: The data collector noted whether the Soldier entered the exclusion area. This measure can also be corroborated by the NavCom data logs.
- Target detection: The data collector noted each target that was located by the Soldier.
- Weapon handling: The data collector noted each time the Soldier took a hand off of his/her weapon.
- Interactions with visual display: The data collector noted each time the Soldier flipped down the visual display. Each Soldier was told to keep the visual display flipped up when not in use.
- Stopping behavior: The data collector noted each time the Soldier stopped and the reason why. In addition, the NavCom system also logged stopping behavior.

3.4.2 Subjective Measures

After each session, Soldiers responded to a National Air and Space Administration Task Load Index (NASA TLX) workload rating form (see Appendix D).

After each experiment condition, Soldiers responded to a questionnaire to assess equipment characteristics and operational relevance associated with that condition. Questionnaires included semantic differential and Likert-based rating scales to assess user perceptions of tactor characteristics and operational issues (see Appendix E for questionnaire forms). After completing both experiment conditions, Soldiers completed a final questionnaire regarding comparisons of both system conditions.

After completing both experiment conditions, Soldiers completed a questionnaire that asked them to assess the training they received prior to participating in the experiment.

4. Results

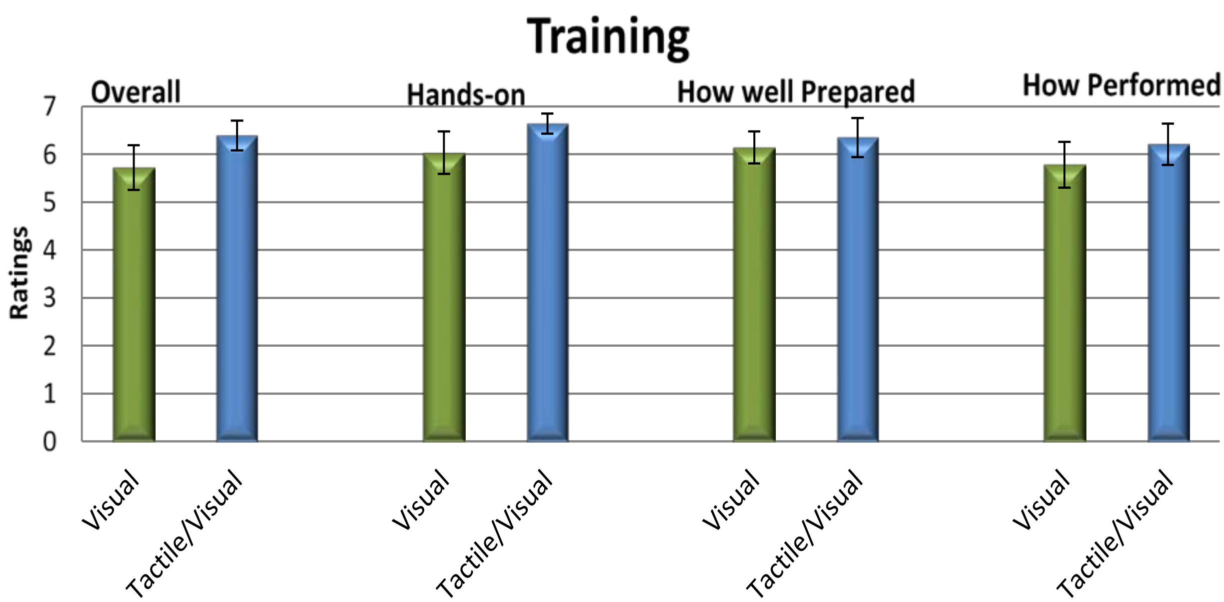
The following section provides descriptive statistics (means, standard deviations [SDs]) and inferential tests of significance based on repeated measures general linear model (GLM). In addition to the F and p statistic associated with hypothesis testing, we also provide a measure of effect size, partial eta square ($\eta\rho^2$), to better interpret the practical significance of differences between conditions. In addition, we provide visual representation of the 95% confidence intervals (CIs) within the bar graphs, which indicate the precision of the mean as it generalizes to the population (i.e., the range estimated, with 95% confidence, to include the “true” mean).

4.1 Training

Soldiers were asked about quality of training for both conditions. Table 5 provides means and SDs of 7 semantic different initial ratings related to training, preparedness, and self-efficacy, where 1 = extremely ineffective/unprepared to 7 = extremely effective/prepared. These values are portrayed in Fig. 17. Values indicate that the Soldiers felt they were well trained and prepared for experiment task demands. Ratings were somewhat higher regarding the tactile system.

Table 5 Mean ratings of training-related items for visual and tactile-visual conditions

Item	Visual-Only Mean (SD)	N	Tactile-Visual Mean (SD)	N
Overall effectiveness of training	5.72 (1.427)	36	6.39 (0.964)	36
Hands-on training	6.03 (1.362)	36	6.64 (0.639)	36
How prepared did you feel?	6.14 (1.018)	36	6.35 (1.252)	36
How well do you think you performed?	5.78 (1.456)	36	6.21 (1.321)	36



Note: Error bars represent 95% CI.

Fig. 17 Mean ratings of training-related questions

4.2 Navigation Time for Total Course and Across All 3 Legs

4.2.1 Total Navigation Time

Table 6 compares courses A and B by providing the means and SDs for the time to navigate the complete route by course and by system. Analysis of variance (ANOVA) analyses showed no significant difference between course A and B with regard to visual condition times ($F_{1, 34} = 1.885$, $p = 0.179$, $\eta\rho^2 = 0.053$) or tactile/visual condition times ($F_{1, 34}$, $= 0.092$, $p = 0.764$, $\eta\rho^2 = 0.003$).

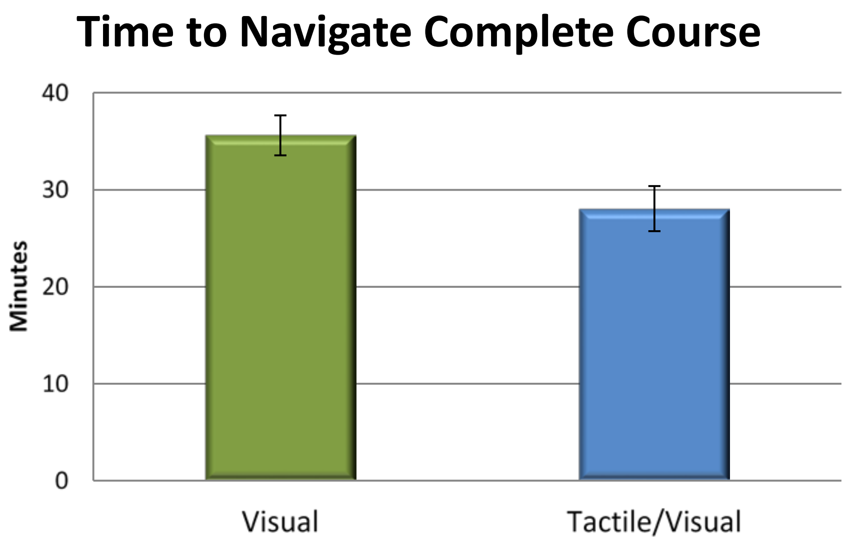
Table 6 Mean time to complete route by course and by condition

Course	Condition	Mean Time (min) to Navigate Complete Course (SD)	N
A	Visual	33.866 (5.50)	18
	Tactile/visual	27.969 (6.99)	18
B	Visual	36.658 (6.65)	18
	Tactile/visual	28.671 (6.91)	18

Table 7 compares visual and tactile/visual conditions by providing the means and SDs for the time to navigate the complete route (i.e., all 3 legs), using the visual versus the tactile/visual systems. Times were significantly faster in the tactile/visual condition ($F_{1, 35} = 24.452$, $p < 0.001$, $\eta\rho^2 = 0.411$). Descriptive data are provided in Table 7 and Fig. 18.

Table 7 Means and SDs for time to navigate complete course (i.e., all 3 legs), by visual and tactile/visual systems

Condition	Mean time (min) to Navigate Complete Course (SD)	N
Visual	35.611 (6.268)	36
Tactile/visual	28.054 (7.128)	36



Note: Error bars represent 95% CI.

Fig. 18 Mean time it took for Soldiers to navigate the complete course

4.2.2 Navigation Time by Leg

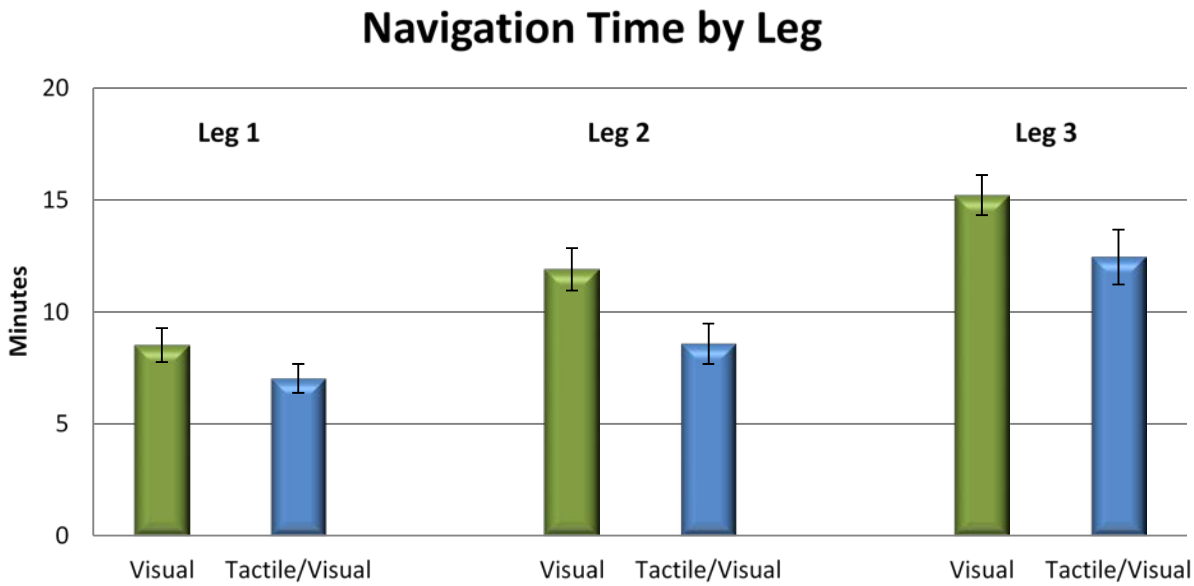
Table 8 provides the means and SDs for the times (in minutes) associated with each leg by condition. The visual condition was associated with slower times for each leg as portrayed in Table 9. These times were significantly different for each leg and was most marked for leg 2, obstacle negotiation without messages, which was associated with a larger effect size, $\eta\rho^2$. These effects are portrayed in Fig. 19.

Table 8 Mean time and SDs to complete each leg by condition

Condition	Means and SD for Time to Navigate (min)			
	Leg 1	Leg 2	Leg 3	N
Visual	8.504 (2.303)	11.896 (2.879)	15.212 (2.766)	36
Tactile/visual	7.029 (1.986)	8.578 (2.765)	12.447 (3.759)	36

Table 9 Repeated measures ANOVA, visual vs. tactile/visual by leg

Legs	$F_{1, 35}$	p-value	$\eta\rho^2$
Leg 1 = Tactical movement w/ messages	6.86	0.013	0.164
Leg 2 = Obstacle negotiation w/o messages	30.05	<0.001	0.462
Leg 3 = Target detection w/ messages	15.52	<0.001	0.307



Note: Error bars represent 95% CI.

Fig. 19 Mean time (in minutes) it took to complete each leg of the course

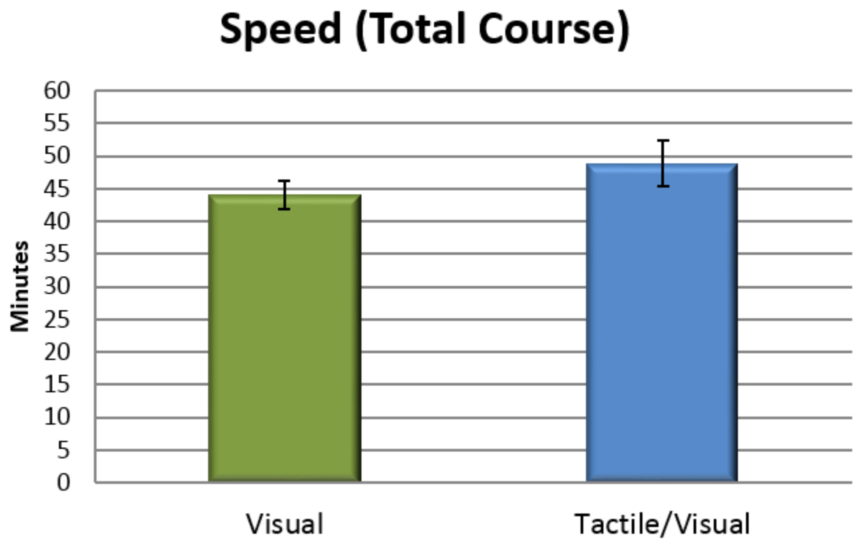
4.3. Navigation Speed

4.3.1 Navigation Speed (Total Course)

Table 10 provides the means and SDs for measures of speed (meters/minute) by condition. Faster speeds were associated with the tactile/visual condition (F 1, 35 = 6.052, $p = 0.019$, $\eta\rho^2 = 0.147$). These measures are represented in Fig. 20.

Table 10 Means and SDs for measures of speed, by visual and tactile/visual conditions

Condition	Means and (SD) for Speed (m/min)	N
Visual	44.050 (6.368)	36
Tactile/visual	48.907 (10.451)	36



Note: Error bars represent 95% CI.

Fig. 20 Time (m/min) it took to complete the total course

4.3.2 Navigation Speed by Leg

Table 11 provides the means and SDs for measures of speed (meters per minute) by leg for each condition. Mean speeds were higher for the tactile/visual conditions for all legs. These differences were statistically significant for legs 2 and 3 (see Table 12). Differences are portrayed in Fig. 21.

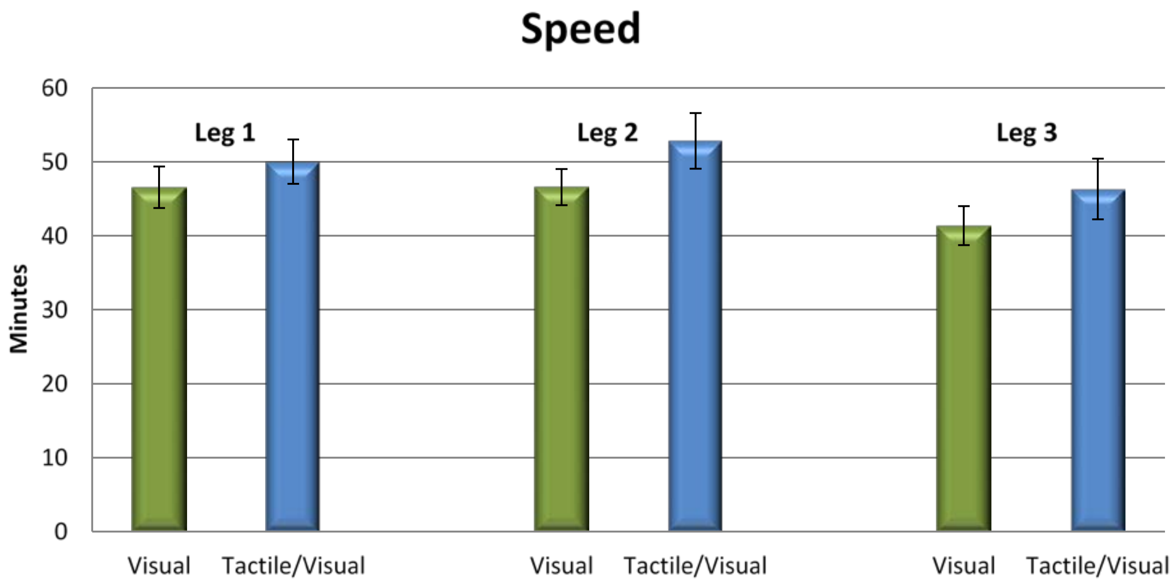
Table 11 Means and SDs for measures of speed (m/min) by leg for the visual and tactile/visual conditions

Condition	**Speed (m/min)**			
	Leg 1 Tactical movement w/ messages	Leg 2 Obstacle negotiation w/o messages	Leg 3 Target detection w/ messages	N
Visual	46.564 (8.64)	46.587 (7.435)	41.364 (8.068)	36
Tactile/visual	50.023 (9.171)	52.843 (11.562)	46.322 (12.538)	36

Table 12 Results (speed) associated with repeated measures ANOVA, comparing the visual and tactile/visual conditions by leg

Legs	**F 1, 35**	**p-value**	**$\eta\rho^2$**
Leg 1 = Tactical movement w/ messages	2.36	0.133 (ns)	0.063
Leg 2 = Obstacle negotiation w/o messages	7.94	0.008	0.185
Leg 3 = Target detection w/ messages	4.36	0.044	0.111

Note: ns = not significant.



Note: Error bars represent 95% CI.

Fig. 21 Speed (m/min) of completion

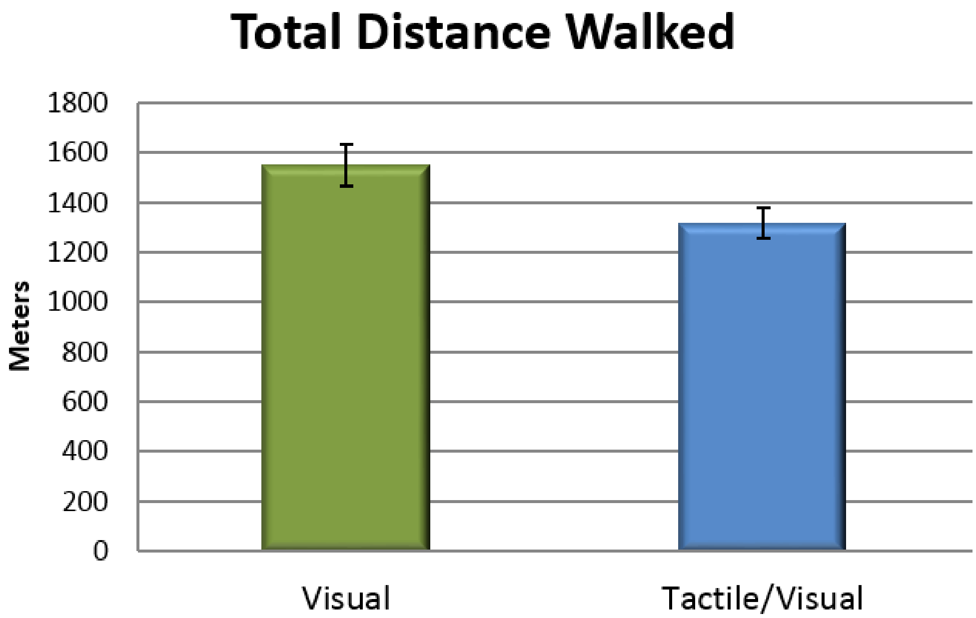
4.4. Distance Walked

4.4.1 Total Distance Walked by Each Soldier

Table 13 provides the means and SDs regarding the total distance walked by each Soldier, for the visual and tactile/visual conditions. It can be seen that the Soldiers walked, on average, a significantly shorter distance (F 1, 35 = 17.871, $p < 0.001$, $\eta\rho^2 = 0.338$). Differences are shown in Fig. 22.

Table 13 Means and SDs for total distance walked for each condition

Condition	Mean Distance (m) Walked to Navigate Complete Course (SD)	N
Visual	1549.010 (252.887)	36
Tactile/visual	1316.506 (189.863)	36



Note: Error bars represent 95% CI.

Fig. 22 Mean distance walked to complete the course

4.4.2 Mean Distance Walked by Leg

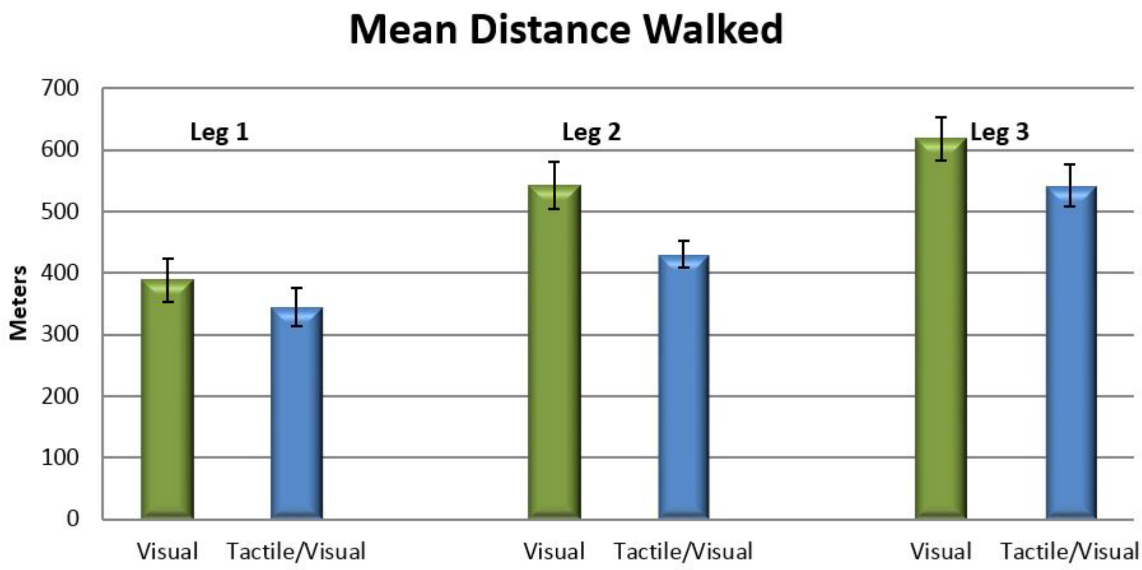
Table 14 provides the means and SDs for the mean distance walked by Soldiers by each leg. Distances were longer for the visual condition. The differences between the visual and tactile/visual conditions were significant for legs 2 and 3 (see Table 15). These differences are portrayed in Fig. 23.

Table 14 Mean distance walked, visual vs. visual/tactile by leg

Condition	**Mean Distance walked (m)**			
	Leg 1 Tactical movement w/ messages	Leg 2 Obstacle negotiation w/o messages	Leg 3 Target detection w/ messages	N
Visual	388.301 (105.72)	543.020 (117.378)	617.688 (107.192)	36
Tactile/visual	344.392 (94.561)	430.291 (66.167)	541.822 (102.450)	36

Table 15 Legs 2 and 3 were significant

Legs	**F 1, 35**	**p-value**	**$\eta\rho^2$**
Leg 1 = Tactical movement w/ messages	2.44	0.065 (ns)	0.065
Leg 2 = Obstacle negotiation w/o messages	24.69	<0.001	0.414
Leg 3 = Target detection w/messages	9.80	0.004	0.219



Note: Error bars represent 95% CI.

Fig. 23 The mean distance (in meters) walked during each leg of the course

4.5 Path Ratio for Total Course and Across All 3 Legs

The path ratio compares the actual mean distance walked by Soldiers to the shortest (i.e., straight line) route (including the interim waypoints). The actual mean distance will be longer than the ideal shortest route due to terrain obstacles (e.g., gullies, brambles). At the same time, distance can also be even longer due to Soldier disorientation and unintended movements in the wrong direction. Table 16 provides the ideal distance as represented by a straight line route. Table 17 provides the ratio data between the means for actual distance compared with the straight-line route by course and by condition. The larger the value, the greater the distance walked. Fig. 24 provides overall path ratio values by condition.

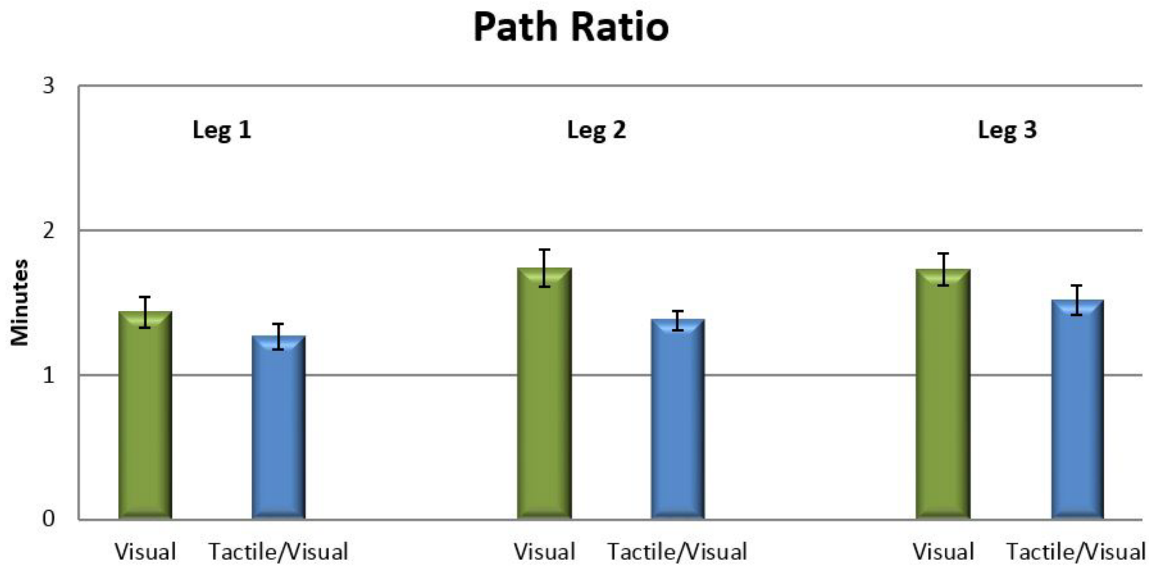
Table 16 Path ratio for total course

Leg	Course A Visual	Course B Visual
Straight line distance ideal shortest route	957.07	926.43
Mean actual distance walked	1,482.53 (SD 222.7)	1,615.48 (SD 269.6)
Path ratio	1.549 (SD 0.233)	1.744 (SD 0.291)
	Tactile/Visual	**Tactile/Visual**
Mean actual distance walked	1,257.60 (SD 190.6)	1,375.40 (SD 174.7)
Path ratio	1.314 (SD 0.199)	1.485 (SD 0.189)

Table 17 Path ratio: ratio of the actual distance walked to the shortest ideal straight line path between waypoints

Condition	Path Ratio: Actual Distance Walked (Ideal)	N
Visual	1.646 (0.2778)	36
Tactile/visual	1.399 (0.2099)	36

Note: Significance F 1, 35 = 15.781, $p < 0.001$, $\eta\rho^2 = 0.311$.



Note: Error bars represent 95% CI.

Fig. 24 Mean results (path ratio) by leg and by visual and tactile/visual conditions

Table 18 provides the means and SDs for path ratio data (i.e., the ratio between the average distance walked/straight line distance) by leg. The path ratio results show that the tactile/visual system was associated with shorter distances, particularly in leg 2. Table 19 provides results of the repeated measures ANOVA. The effect size, $\eta\rho^2$, was quite large for leg 2. These differences are portrayed in Fig. 24.

Table 18 Means and SD for path ratio results for each navigation leg, by condition

Condition	Path Ratio			N
	Leg 1 Tactical movement w/ messages	Leg 2 Obstacle negotiation w/o messages	Leg 3 Target detection w/ messages	
Visual	1.434 (0.327)	1.738 (0.382)	1.729 (0.341)	36
Tactile/visual	1.267 (0.269)	1.376 (0.213)	1.517 (0.310)	36

Table 19 Results (path ratio) associated with repeated measures ANOVA, comparing the visual and tactile/visual conditions by leg

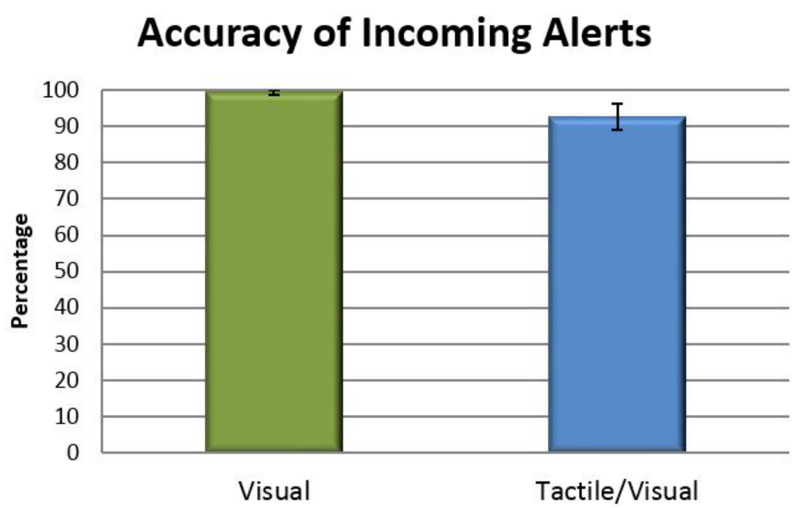
Legs	F 1, 35	p-value	$\eta\rho^2$
Leg 1 = Tactical movement w/messages	4.80	0.035	0.121
Leg 2 = Obstacle negotiation w/o messages	23.63	<0.001	0.403
Leg 3 = Target detection w/messages	6.68	0.014	0.160

4.6 Recognition of Incoming Alerts

Table 20 provides means and SDs for accuracy of interpreting incoming alerts. In the visual condition, the Soldier simply reads the text message on the visual display screen; therefore, accuracy was expected to be near 100%. Repeated measures ANOVA showed the difference was significant ($F_{1, 35} = 13.02$, $p = 0.001$, $\eta\rho^2 = 0.271$). Figure 25 shows the percentages of correct responses.

Table 20 Means and standard deviations for accuracy of incoming messages for visual and tactile/visual conditions

Condition	% Correct	N
Visual	99.444 (1.934)	36
Tactile/visual	92.722 (10.785)	36



Note: Error bars correspond to 95% CI.

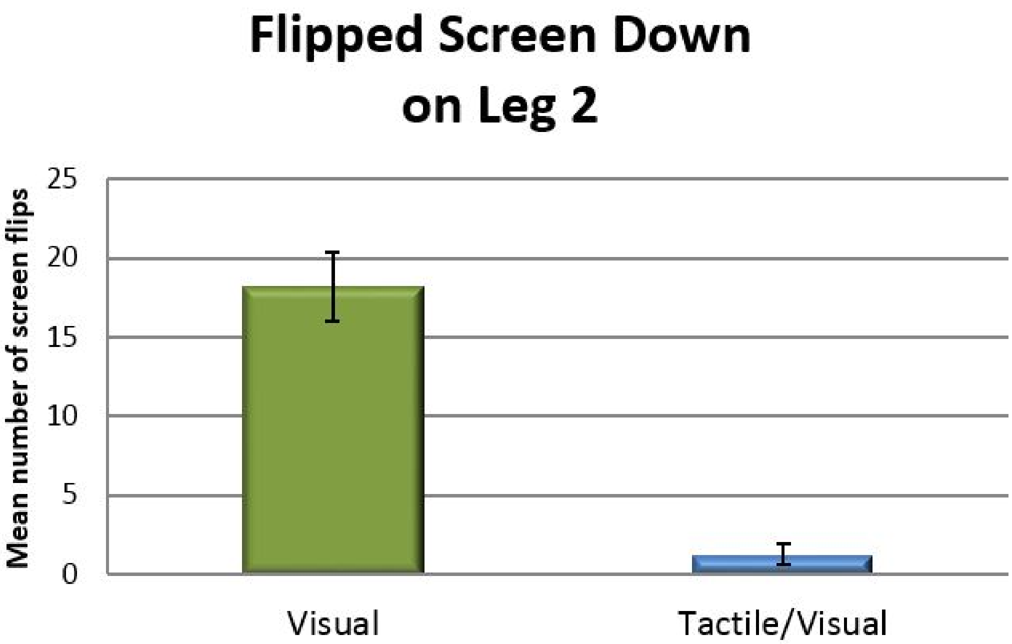
Fig. 25 The percentage of correct responses of incoming alerts

4.7 Interactions with Visual Display

Table 21 provides the mean number of times the Soldier flipped the screen down during the navigation-only leg. Results are similar to the mean number of times the Soldier stopped, indicating that the Soldier usually stopped when he or she looked at the visual display. This difference was statistically significant ($F_{1, 35} = 267.995$, $p < 0.001$, $\eta\rho^2 = 0.884$) and is portrayed in Fig. 26.

Table 21 Mean number of display flips

Condition	Number of Times Flipped Down Screen (Navigation Leg)	N
Visual	18.22 (6.685)	36
Tactile/visual	1.28 (2.051)	36



Note: Error bars indicate 95% CI.

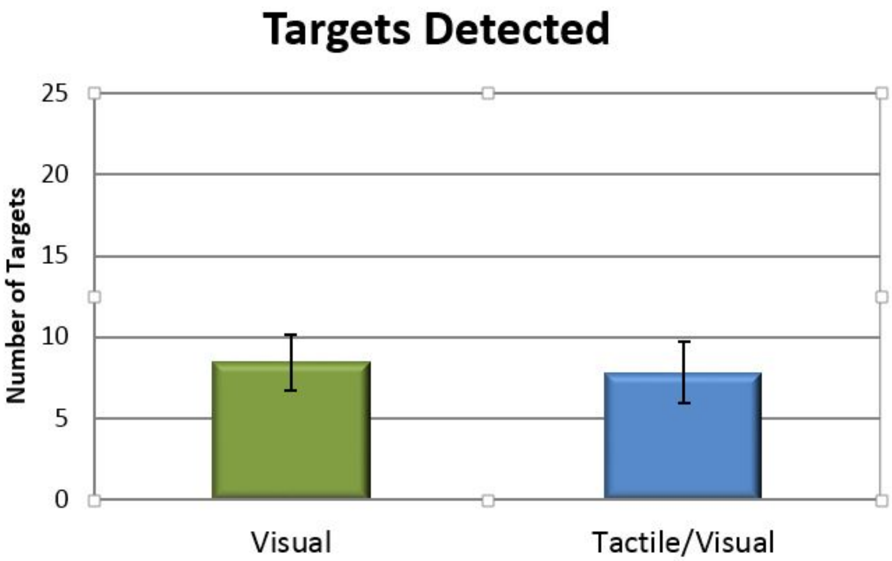
Fig. 26 The mean number of times a Soldier flipped down his/her screen (navigation-only leg)

4.8 Number of Targets Detected

Table 22 provides the means and SDs for the number of silhouette targets identified in leg 3. The difference between the visual and tactile/visual conditions was not significant. (F 1, 35, = 0.372, p = 0.546, $\eta\rho^2$ = 0.011). One can see that the SD values are large, indicating a large degree of variation due to individual differences among the Soldiers. The values are portrayed in Fig. 27.

Table 22 Mean and SD for number of targets detected in leg 2 by visual and tactile/visual conditions

Condition	Number of Targets Detected	N
Visual	8.44 (5.196)	36
Tactile/visual	7.83 (5.675)	36



Note: Error bars represent 95% CI.

Fig. 27 The mean number of targets detected by the Soldier

4.9. NASA-TLX

Table 23 provides means and SDs of direct ratings of NASA-TLX factors: mental workload, physical workload, temporal workload (i.e., time pressure), level of effort, and level of frustration experienced while using the equipment in visual and tactile/visual conditions. The NASA-TLX factor of performance is a self-rating of how well they think they did and, as such, is more reflective of self-efficacy than workload per se. It can be seen that ratings of workload were lower and ratings of how well they performed were higher in the tactile/visual condition (see Fig. 28).

Table 23 Comparison of NASA-TLX means and SDs for visual and tactile/visual conditions

Condition	Mental	Physical	Temporal	Effort	Frustration	Performance
Visual only	4.50 (2.42)	3.17 (1.97)	3.17 (1.98)	4.03 (2.26)	3.44 (2.67)	7.50 (2.37)
Tactile/visual	3.00 (2.03)	2.67 (1.80)	2.78 (2.17)	2.75 (1.98)	2.06 (1.69)	8.89 (1.51)

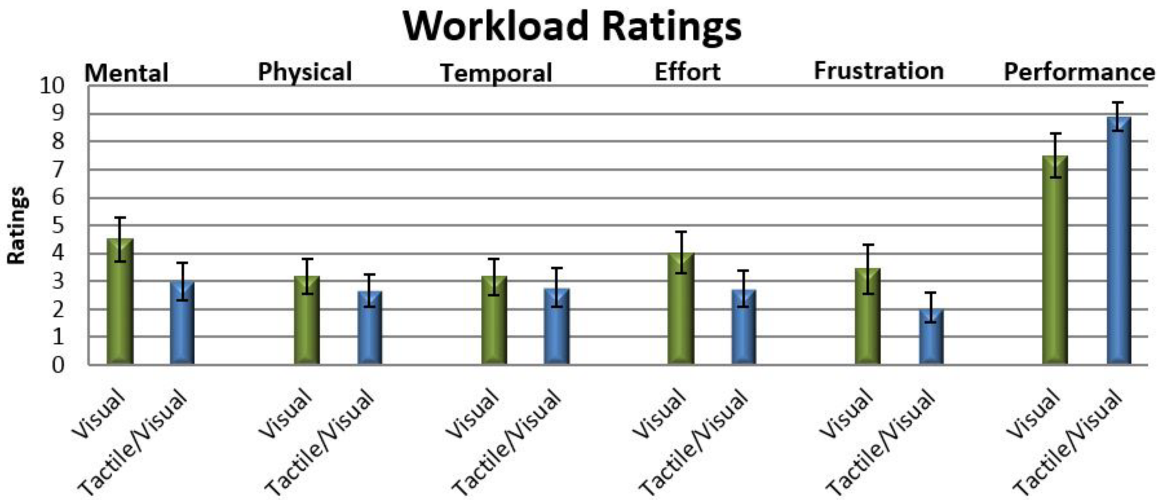


Fig. 28 Self-reported workload data

Table 24 provides results from paired comparison t-tests. These comparisons showed significant differences between the visual versus tactile/visual conditions, for mental demand, effort, frustration, and perceptions of performance. Mental demand, frustration, and effort were lower, while perceptions of performance were higher in the tactile/visual condition.

Table 24 Paired comparison for NASA TLX

Condition	Mental	Physical	Temporal	Effort	Frustration	Performance
Visual	3.50	1.75	1.51	3.20	2.992	3.066
Tactile/visual	001[a]	089	140	003[a]	005[a]	004[a]

[a] $p < 0.01$

Table 25 provides descriptive results for the measure of spatial ability (i.e., cube comparison test).

Table 25 Descriptive results for the cube comparison measure of spatial ability

Measure	N	Min.	Max.	Mean (SD)
Cube comparison test	36	–5	18	4.42 (4.56)

Analyses regarding navigation speed were run with the measure of spatial ability as a covariate. Results indicate no moderating effect due to spatial ability.

In addition, spatial ability was analyzed as a covariate with regard to TLX ratings. Results indicate spatial ability had no interaction with the TLX ratings for visual versus tactile/visual (see Table 26).

Table 26 Repeated-measures GLM for NASA TLX scores between visual and visual/tactile, with spatial as a covariate

Effect	F	Df	P	$\eta\rho^{2\,a}$	Observed Power
Mental	4.98	1, 34	0.03	0.128	0.583
Mental spatial[a]	0.11	1, 34	0.74	0.003	0.062
Physical	1.216	1, 34	0.278	0.035	0.188
Physical spatial[a]	0.033	1, 34	0.857	0.001	0.054
Temporal	0.384	1, 34	0.54	0.011	0.092
Temporal spatial[a]	0.407	1, 34	0.528	0.012	0.095
Effort	7.824	1, 34	0.008	0.187	0.776
Effort spatial[a]	0.57	1, 34	0.455	0.017	0.114
Frustration	8.066	1, 34	0.008	0.192	0.788
Frustration spatial[a]	1.013	1, 34	0.321	0.029	0.165
Performance	7.947	1, 34	0.008	0.189	0.782
Performance spatial[a]	0.828	1, 34	0.369	0.024	0.143

[a] Partial eta square

4.10 Soldier Feedback: Ratings and Summary Comments

Soldiers provided feedback in the form of comments and responses to rating scales. Ratings scales were primarily semantic differential scales ranging from 1 = very ineffective, uncomfortable, difficult (etc.) to 7 = very effective, comfortable, easy. They also responded to statements where they respond as to the extent of agreement using a 7-point Likert scale ranging from 1 = disagree completely to 7 = agree completely.

4.10.1 Mount/Comfort

Soldiers wore the same system in both conditions, including the tactile belt. The only difference is that the tactors were either turned on or off. Table 27 provides means and SDs of ratings related to the mounting of the visual system and overall comfort of the entire system. Ratings were based on a 7-point semantic differential scale ranging from 1 = extremely ineffective/uncomfortable to 7 = extremely effective/comfortable. All mean ratings were high for aspects of the visual and tactile systems.

Table 27 Mount/comfort comments

Visual Items	Mean (SD)	N
Effectiveness of the front-mount in general	6.33 (1.095)	36
Ease of flipping the display up/down	6.08 (1.251)	36
Comfort of the mounting mechanism	6.08 (1.251)	36
Stability of display during movements	6.47 (0.774)	36
Tactile-Visual items	**Mean (SD)**	**N**
Comfort of tactile belt	6.56 (0.652)	36
Adjustability of tactile belt	6.17 (1.134)	36
Fit of tactile belt	6.42 (0.841)	36

4.10.2 Visual Display Readability

Table 28 provides means and standard deviations of 7-point semantic differential ratings related to readability of the visual display at night ranging from 1 = extremely difficult to 7 = extremely easy. All ratings regarding readability were high, indicating strong agreement that the visual display was very easy to read.

Table 28 Visual display comments

Visual Items	Mean (SD)	N
Ease of reading display map at night	6.56 (0.705)	34
Ease of reading display text at night	6.62 (0.604)	34
Ease of reading display icons (symbols) at night	6.50 (0.826)	34

4.10.3 Visual Display Effectiveness

Table 29 provides means and SDs of 7-point semantic differential ratings related to interpretability of the visual display at night ranging from 1 = extremely difficult to 7 = extremely easy. All ratings regarding readability were high, indicating strong agreement that the visual display was very easy to interpret, and the audio alerts were extremely helpful.

Table 29 Visual display effectiveness means and SD

Visual Items	Mean (SD)	N
Knowing where you are on the map	6.11 (1.051)	35
Navigating to waypoint (knowing the direction to go)	6.03 (1.224)	35
Knowing how far to next waypoint	5.51 (1.755)	35
Able to maintain awareness of your surroundings	5.37 (1.437)	35
Effectiveness of audio alerts	6.31 (0.867)	35

4.10.4 Visual Display Frequency of Use

Soldiers described their frequency of use of the visual display when using the visual system, using a 7-point scale ranging from 1 = not at all to 7 = very frequently. The mean rating was 5.14 (SD = 1.192), indicating a relatively high frequency of use. This corresponds to observation-based assessments regarding the number of times they checked their screen. This is in comparison with a mean of 2.24 (SD = 1.135) in the tactile-visual condition, indicating a relatively low frequency of use. Fig. 29 shows the difference in mean ratings between the visual and tactile/visual systems. The difference was significant (paired t-test, $t = 6.880$, $df = 15$, $p < 0.001$).

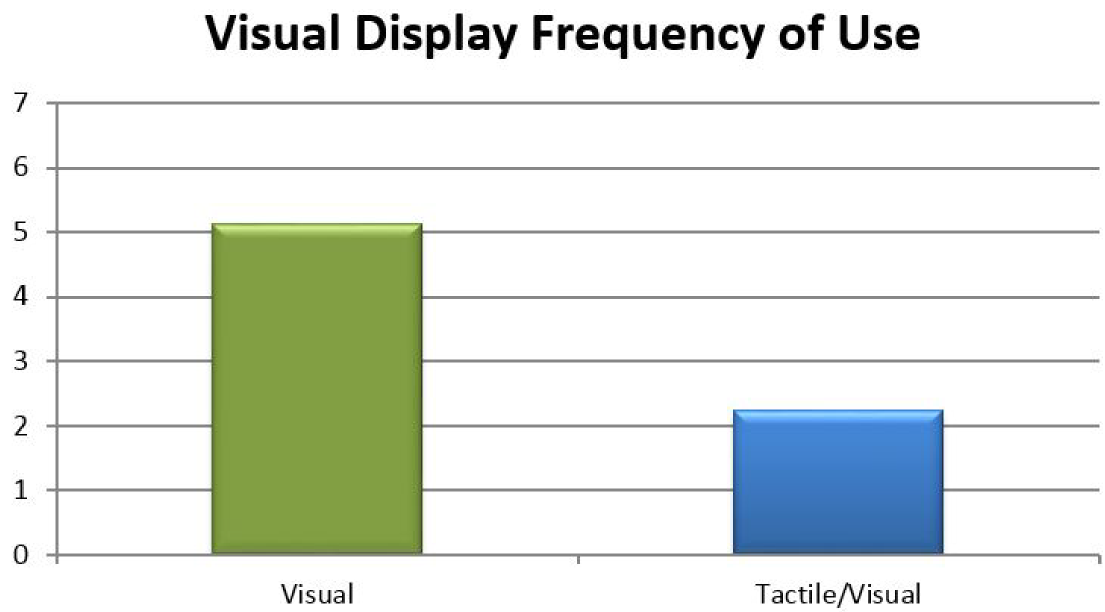


Fig. 29 Mean ratings between the visual and tactile/visual systems

4.10.5 Tactile Display: Ease of Feeling Tactors

Soldiers described the ease or difficulty of feeling tactors, using a 7-point scale ranging from 1 = extremely difficult to 7 = extremely easy. Mean values and SDs are provided in Table 30. Results indicate that Soldiers found the tactors to be very to extremely easy to perceive.

Table 30 Tactile recognition means and SDs

Tactile Items	Mean (SD)	N
Ease of feeling single-tactor direction cues	6.67 (0.793)	36
Ease of feeling tactor patterns in general	6.53 (0.774)	36
Ease of knowing you are nearing waypoint	6.64 (0.723)	36
Ease of recognizing “robot wheels are spinning”	6.50 (0.878)	36
Ease of recognizing “robot detected target/threat”	6.33 (1.042)	36
Ease of recognizing “robot battery low”	6.44 (0.969)	36
Ease of recognizing “robot detected NBC”	6.69 (0.668)	36
Ease of recognizing “waypoint reached”	6.67 (0.828)	36
Ease of recognizing “exclusion zone”	6.75 (0.672)	32

4.10.6 Tactile Display: Noise

Soldiers reported the level of noise associated with the tactors using a scale ranging from 1 = extremely noisy to 7 = silent. Results (see Table 31) indicate that the tactors were associated with a small level of noise.

Table 31 Tactile display noise

Tactile Items	Mean (SD)	N
How noisy were the single tactor direction cues?	4.46 (1.291)	35
How noisy were the tactor patterns (communications)?	4.35 (1.368)	34

Soldiers were also asked how far away, in meters, they thought the noise of the tactors could be heard. Responses varied a great deal, around a mean of 16.49 (SD = 16.216).

4.10.7 Tactile Display Cues: Characteristics

Soldiers were asked whether some patterns easier to feel than others; 78% said yes. They were also asked which patterns were easier to feel. Table 32 provides a breakdown of their responses. Soldiers could choose more than one signal. Results indicate the NBC signal was most frequently chosen as easy to feel.

Table 32 Tactile display cues: characteristics

Spinning Wheels	Battery Low	Target Detected	NBC
18	13	11	24

4.10.8 Tactile Display: Likert Ratings

Soldiers responded to the statements listed in Table 33 by indicating the degree of their agreement based on a Likert scale ranging from 1 = strongly disagree to 7 = strongly agree. Ratings were generally high for positive statements and low for negative statements, such as "The tactile signal was annoying".

Table 33 Tactile display: Likert ratings means and SDs

Tactile Items	Mean (SD)	N
"It was easy to know the direction of next waypoint."	6.69 (0.624)	36
"It was easy to know I was getting close to waypoint."	6.44 (0.773)	36
"It was easy to feel each tactile signal in general."	6.22 (1.017)	36
"It was easy to feel each tactile signal while walking."	6.08 (1.131)	36
"It is easy to detect tactile communication while I am moving."	5.97 (0.985)	35
"It was easy to feel each tactile signal while performing IMT[a] maneuvers."	5.90 (1.491)	31
"It was easy to understand what each signal meant."	5.86 (1.268)	36
"I was very certain what each signal meant."	5.86 (1.246)	36
"The tactile system should be used for critical information that represents imminent danger."	5.83 (1.000)	36
"The tactile cues help keep my attention on surroundings."	5.67 (1.568)	36
"I recognized each signal immediately."	5.67 (1.394)	36
"The tactile cues are a good substitute when radios cannot be used."	5.64 (1.222)	36
"The tactile cues can be useful for Soldiers to communicate."	5.58 (1.442)	36

Table 33 Tactile display: Likert ratings means and SDs (continued)

Tactile Items	Mean (SD)	N
"The tactile system should repeat the message until I have acknowledged that I have received it."	5.19 (1.431)	36
"The tactile system should warn me with a tactile signal before I receive a communication."	5.17 (1.630)	36
"The tactile system should convey a sense of priority of the communication."	5.14 (1.417)	36
"The tactile system should convey a sense of urgency of the communication."	5.14 (1.313)	36
"It would be confusing to receive more than one tactile message in a row."	5.11 (1.676)	35
"A moving tactile pattern should indicate an action cue (e.g., get down, move out)."	5.03 (1.790)	35
"The tactile system should be used to communicate any command that could be conveyed through hand and arm signals."	4.83 (1.732)	36
"I would like the ability to create my own commands that could be used with this tactile system (e.g., create commands based on unit SOPs)."[b]	4.74 (1.945)	35
"The tactile cues are too noisy for covert missions."	4.36 (1.775)	36
"It is easy to miss a message from the tactile system if I am focused on something else.	4.17 (1.823)	35
"The tactile cues are too noisy for regular patrols."	3.53 (1.383)	36
"The tactile signal should be stronger."	3.39 (1.554)	36
"The tactile signal was annoying."	2.42 (1.592)	36
"The tactile signal felt ticklish."	2.33 (1.373)	36

[a] IMT = individual movement technique; [b] SOP = standard operating procedure

Soldiers were also asked the following: Given the potential advantages of a tactile system (e.g., light security, noise-free, intuitive directions), and assuming it was further engineered to be combat-ready (rugged, reliable), how might the system be useful for the following (see Table 34)? Soldiers responded using a 7-point scale ranging from 1 = extremely ineffective to 7 = extremely useful. Mean ratings indicated high degrees of operational relevance across a variety of missions. Table 35 details the benefits by Soldier position.

Table 34 Operational relevance of system concept

Operational Relevance of System Concept For:	Mean (SD)	N
Infantry in general	6.29 (1.017)	35
Night patrol/overwatch	6.06 (1.083)	35
Day patrol/overwatch	5.80 (1.183)	35
Road marches	5.49 (1.788)	35
To maintain radio silence	6.09 (1.222)	35
When visibility is low	6.60 (0.736)	35

Who would benefit from having the tactile belt capability?

Table 35 Benefit by Soldier position within the squad

Rifleman	TL	SL	PL	PSGT	Point Man	Other
19	20	19	19	19	30	2

Note: TL = team leader; SL = squad leader; PL = platoon leader; PSGT = platoon sergeant.

4.10.9 Final Questionnaire

Soldiers responded to a short final questionnaire that asked for an overall ratings of effectiveness (7-point semantic differential scale ranging from 1 = extremely negative to 7 = extremely positive) for the visual and the tactile/visual systems. Table 36 provides the means and SDs. The tactile/visual system was rated significantly higher (F 1, 34 = 16.514, $p < 0.001$, $\eta\rho^2 = 0.327$). Figure 30 shows overall effectiveness rating.

Table 36 Means and SDs for overall rating of effectiveness for visual and tactile/visual systems

System	Mean Overall Rating
Visual	4.89 (1.906)
Tactile/visual	6.54 (0.950)

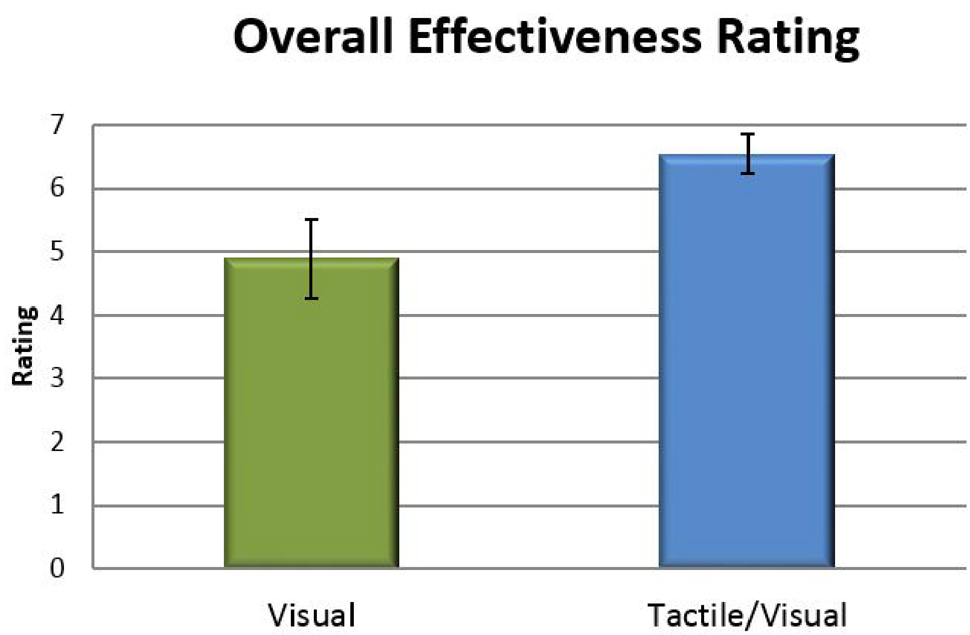


Fig. 30 Overall effectiveness by condition

4.10.10 Comments from Final Questionnaire

All comments are listed in Appendix E. A summary is provided here.

Table 37 shows the answers to the following question: How would you recommend using the tactile belt (which people, what situations)?

Table 37 Recommendations for use of tactile belt

Who/Comment	Number
Leaders	2
Platoon leader	2
Platoon sergeant	1
Point man	9
Team leader	3
Squad leader	3
All members of squad	8
All infantry/scouts	4
Rangers, snipers, combat engineers, combat MOS[a]	1
Low noise/radio silence/stealth	3
Night/poor visibility	6
Any	7
Not often	1
Patrols/movements	7
Combat	2
Tactical movement	2
Infiltration/recon	1

[a]MOS = military occupational specialty

Table 38 shows the answers to the following question: What would be some useful commands for the tactile belt system?

Table 38 Useful commands

Comment	Number
Halt	7
File	4
Wedge	4
Change formations	4
Get down	4
Contact left/right; shift fire	2
Pull security	1
Move	5
Direction (to look)	2
Enemy spotted	7
IED[a]	2
NBC	1

[a] IED = improvised explosive device

Table 38 Useful commands (continued)

Comment	Number
Danger area	1
Final waypoint	1
Any hand signal	3
Get attention from another Soldier	1
Hold position	1
Under fire	1
Casualty	2
Rally point	1
FOBs[b]	1
Friendlies at (grid)	1
Need help	1
Robot location	2
Obstacles	1
Check Soldier status/ammo check	1
Any basic command	1
No commands during firefight	1

[b] FOBs = forward operating bases

Table 39 shows the answers to the following question: What are potential advantages of the Tactile/visual system?

Table 39 Potential advantages

Comment	Number
Silent communications	7
Land navigation (ease of, no thought involved, etc.)	12
Faster	14
When multitasked (e.g., moving and scanning)	2
Safer (keeps you out of danger, etc.)	2
Better situation awareness	5
Do not have to check map as often	5
Hands free	1

Table 40 shows the answers to the following question: What are main concerns that need improvement?

Table 40 Main concerns or suggested improvements

Comment	Number
Keep it simple	1
Make quieter	11
More rugged/weatherproof	7
Better way to secure belt (integrate)	4
Stronger vibrations	1
Battery life	1
More training	1
Remove visual display	1
Breathability of fabric	1
Adjust tactor signals so not constant	1
Make affordable	1
Better Velcro/more secure latches	1
Visual; use red light	1
Visual; meters	4
Visual-dimmer display	4
Map accuracy	1
Satellite signal	1

5. Discussion

Researchers at the US Army Research Laboratory evaluated a system for navigation and communication that is relatively hands-, eyes-, and mind-free to aid Soldiers in the field. The objective of this experiment was to empirically evaluate simultaneous presentations of navigation and robot communication/monitoring using tactile patterns comprising 2 different types of advanced tactors. The 36 Soldiers participating in these experiments used a NettWarrior visual display concept, once with the tactile system turned on and once with it turned off, during operationally relevant scenarios involving route navigation, interpretation of incoming messages, obstacle avoidance, and visual search for silhouette targets. The tactile system consisted of a lightweight belt around their torso containing miniature vibrotactile tactor actuators. The belt provided vibratory (i.e., tactile) cues, allowing a Soldier to navigate to map coordinates and receive communications while still carrying a weapon.

Performance-based outcomes showed that when the tactile system was turned on (i.e., tactile/visual condition), Soldiers completed the navigational tasks faster, walked shorter distances, and strayed away from the ideal route less. Additionally, Soldiers stopped fewer times and viewed their display significantly less while using the tactile/visual system. Soldiers also reported less workload associated with the use of the tactile/visual system as compared with the visual system alone.

For the experiment design, two 900-m routes were developed to be similar in task demand and characteristics. Three major waypoints comprised each route, each indicating the end of a navigation leg. Each Soldier navigated each route in 1 of 2 conditions: once with the tactile system turned off (i.e., visual condition) and once with the tactile system turned on (i.e., tactile/visual condition). Each leg also had the same number of sub-waypoints, which allowed the Soldier to avoid areas designated as potential threat (e.g., minefields).

Each navigation leg had different task demands. The first leg, navigation with alerts, had the Soldier navigate to the first waypoint while receiving 12 incoming alerts (i.e., 3 repetitions of 4 different communications). These alerts were displayed either through the visual display (i.e., an audio alert together with text messages) or through interpretations of tactile patterns. The second leg, navigation with exclusion area, had the Soldier navigate through rough terrain while avoiding an exclusion area (i.e., an area with a radius of around 20 m), that crossed the direct straight line path from waypoint 1 to waypoint 2. In this second leg, incoming alerts were not given in order to assess performance and behaviors associated with navigation per se. The third leg, navigation with target detection, had the Soldier navigate from waypoint 2 to the final waypoint while receiving 12 incoming alerts and search for 20 silhouette targets situated along the route, with equal distribution of targets that were close, midrange, and further away.

Training consisted of classroom, hands-on, and practice sessions. Soldiers indicated high levels of satisfaction and preparedness for both systems. Performance results are as follows.

The time to navigate the complete route (all 3 legs) was significantly faster in the tactile/visual condition versus the visual condition by about 7 min for the total route, which averaged around 30 min for 900 m of rough terrain with multiple waypoints. Several factors that account for the faster navigational times. For example, Soldiers did not have to stop to consult their visual display or keep track of their direction or pace count to establish distances traversed.

Differences in navigation times were more pronounced for leg 2 (navigation with exclusion area) and leg 3 (navigation with alerts and target detection), indicating that the contribution of the tactile system was more pronounced when attention demands on the Soldier are higher. In leg 1, the route was more linear and the terrain not as challenging, thus the need for rerouting was potentially lower.

In addition, the total distance walked by each Soldier was significantly shorter when Soldiers used the tactile system, indicating that the use of the tactile/visual system decreased the total distance each Soldier walked to complete the course. The navigational cues felt by the Soldier around their torso led them more directly to the next waypoint leading to shorter distances between waypoints. Results by leg were similar to that of navigation time: Soldiers were significantly aided by the tactile system for legs 2 and 3, where there were greater demands for attention (e.g., rerouting, target detection).

The path ratio is the ratio between the distances that the Soldier actually walked versus the ideal path between waypoints. This ratio was smaller when Soldiers used the tactile system, indicating that the use of the tactile/visual system kept the Soldier closer to the most efficient route, thus also affecting navigation time and navigation distance. With the tactile navigation cues, Soldiers' actual paths were closer to the ideal path. Results by leg were significant for all legs; however, the effect size was particularly large for leg 2, where Soldiers had to reroute around an exclusion zone. Thus the tactile system was particularly effective when the Soldier had more complex navigation demands.

Navigation speed (meters walked per minute) was slower in the visual condition than the tactile/visual condition, indicating that the use of the tactile/visual system decreased the amount of time to complete the total course. Soldiers were able to walk faster with the NavCom system because they did not have to continuously consult their display or keep track of their pace count. Consistent with other indicators of navigation performance, the contribution of the tactile system with regard to speed was significant for leg 2 (navigation with exclusion zone) and leg 3 (navigation with alerts and target detection).

Soldiers interpreted the tactile signals (incoming alerts) with 93% accuracy while on the move and with high visual attention demands. Although the accuracy of incoming alerts was significantly higher when using the visual display, in the visual condition the Soldier merely read the alert from the screen; therefore, it is not surprising that the accuracy was 99%. One tradeoff with regard to accuracy of incoming messages is that the Soldier stopped more often to check the visual display, thus slowing navigation speed and disrupting visual attention from surroundings. The tactile alert was only presented once; it is possible that higher accuracies could be achieved with a repetitive alert that is acknowledged by the Soldier.

The number of times the Soldier stopped across all navigational legs was significantly and extremely higher when Soldiers relied solely on the visual display (i.e., means around 34 times compared with a mean of 1 time when the tactile system was turned on). This was expected due to the necessity of the Soldier in the visual condition to check the display for incoming messages. During leg 2, no incoming alerts were given, and checks of the visual display were for navigational purposes only. Thus, the data indicates that the number of times the Soldier stopped to check his display during leg 2 was still significantly higher in the visual condition (mean = 17.72) versus the tactile/visual condition mean = 1.28). This indicates that Soldiers frequently checked the visual display even when there were no incoming messages, indicating a heavy reliance on the visual display for the sole purpose of navigation. This behavior during leg 2 was also significantly higher in the visual condition versus the tactile/visual condition. Results were very similar to the mean number of times the Soldier stopped, indicating that the Soldier usually stopped when he/she looked at the visual display. Soldier perceptions reflected the same trend, in that Soldiers described their frequency of the visual display use as high (mean = 5.14 of a 7-point scale, where 1 = not at all and 7 = very frequently). In contrast, when the tactile system was available, Soldiers rated the frequency of use of the visual display as low (mean = 2.24).

Target detection performance did not differ significantly when comparing the visual system to the tactile/visual system. The large variation in performance in both conditions indicate that target detection performance is more associated with differences in Soldier abilities. That is, the tactile system did not aid the Soldiers to see more targets but did affect the Soldier's ability to see them faster, given the faster navigation times during this leg. The tactile cueing did not give any information as to where the targets were located.

The NASA TLX self-rated workload ratings were significantly lower for mental workload, level of effort, and level of frustration in the tactile/visual condition versus the visual condition. In addition, the performance rating (how well the Soldiers think they did) was rated as higher when Soldiers used the tactile system.

Soldiers provided feedback on many aspects of equipment use. They rated both systems highly for characteristics related to comfort and fit, with ratings ranging from 6.08 (flipping the screen up/down) to 6.57 (comfort of tactile belt) on a 7.0 semantic differential scale, with 7 = extremely comfortable/effective. The visual display was rated highly for readability at night, ranging from 6.50 to 6.62, where 7 = extremely easy. Ratings of the visual display were also high for the effectiveness of the visual display in terms of knowing where one was, knowing which way to go, and maintaining situation awareness, ranging from 5.51 (knowing how far to next waypoint) to 6.31 (effectiveness of audio alerts). Ratings regarding the ease of feeling the tactors (7-point scale where 1 = extremely difficult and 7 = extremely easy) reflected that Soldiers found the tactors to be easy to feel, with means ranging from 6.33 (ease of recognizing "robot detected threat") to 6.69 (ease of feeling "robot detected NBC"). The NBC signal was most frequently reported as being more easily felt. Tactors were adjusted to be high in volume to make the signals more easily felt. This results in the tactors being somewhat noisy, which the Soldiers noted, rating the noise with a mean of 4.35 (tactor patterns) and 4.46 (single tactors) on a range where 1 = extremely noisy to 7 = silent.

Soldiers also responded to many Likert scale (i.e., agree-disagree) statements, and generally provided high ratings (e.g., agree) for positive statements and low ratings (e.g., disagree) for negative statements. Highest ratings were for ease of knowing direction to next waypoint and ease of feeling tactors. When asked to rate the usefulness of the system for operations, Soldiers provided high ratings across a range of operational scenarios, ranging from road marches (mean = 5.49, where 7 = extremely useful), to "infantry in general" (mean = 6.29). With regard to who should be issued the system, Soldiers indicated all members of a squad, with highest agreement that the point man should have it.

Soldiers also provided many comments regarding the system. Typical positive statements include:

- "It has the ability to send signals quickly and silently. You can do land navigation with no thought involved."
- "A faster way to get to one point to another, and it's a lot quieter than a radio."

- "It is way more effective and faster than conventional land nav. It allows the Soldiers to stay more effective towards threats."
- "Using the belt required less screen use. This prevented my eyes having to readjust to the night."
- "It takes a lot less time; you can pay more attention to your surroundings and be more aware of your surroundings."

At the same time, Soldiers provided insightful comments with regard to how to make the system more combat-ready. The system must be durable, weatherproof, and reliable. Battery and power usage will also be important. Soldiers suggested that the tactors should be adjustable, such that tactor intensity and noise levels can be changed to fit situation demands. Soldiers also suggested that tactile messages should be repeated until the Soldier acknowledges understanding (e.g., push a button). Some Soldiers tended to stop to better interpret the tactile signal. Repeated signaling would reduce the need to stop.

6. Conclusions

This experiment-based evaluation of tactile display technology compared the efficacy of a chest-mounted visual display when used with and without an integrated tactile display. Core conclusions demonstrate the concepts of hands-free, eyes-free, and mind-free.

Under the concept of hands-free and eyes-free, when Soldiers had the tactile system available for use, they used it almost exclusively, which means they were able to keep their hands on their weapons and their eyes on their surroundings rather than an interactive display, increasing their situational awareness. They stopped less to view their displays, thus reducing the interaction with their visual displays.

Demonstrating the mind-free concept, the tactile system improved navigation performance with regard to distance and time. Soldiers reported that they did not have to think about things like pace count or degrees, allowing for a much smoother and faster navigational experience and reducing mental workload, frustration, and effort.

Additionally, Soldiers using the tactile belt for navigation preserved their night vision and increased light security. Although high ratings were given for the use of the tactile navigation on operational relevance, further improvements were identified for combat readiness.

In summary, these results augment collected findings with regard to development of tactile displays for dismounted Soldier performance. Further research is planned to investigate issues affecting the salience (i.e., ease of perception) of tactile cues, following up on recent data collection (Elliott et al., in review). Further investigations are also warranted with regard to ease of learning and recognition as moderated by tactile characteristics.

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Appendix A. Taction Patterns

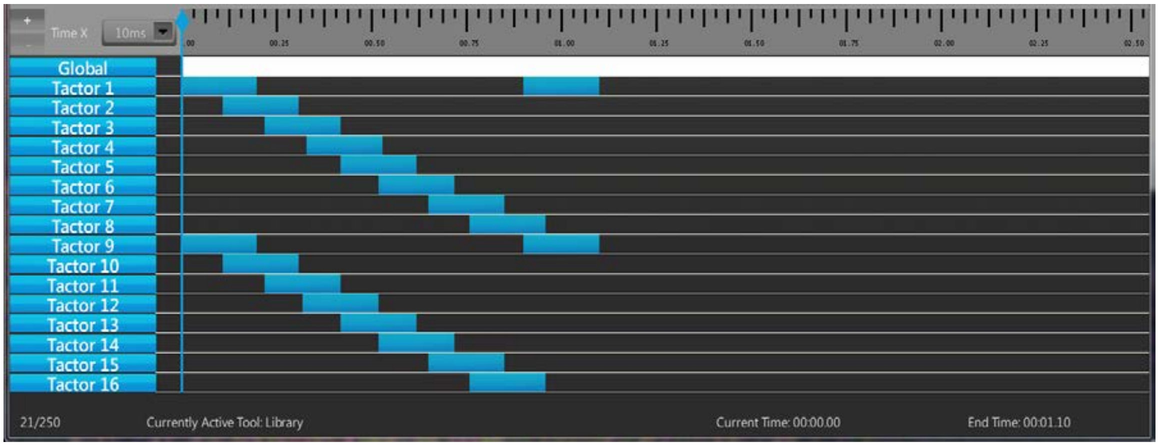
This appendix appears in its original form, without editorial change.

TACTION PATTERNS

TActions are described for the EAI Dual Belt. Tactors 1-8 are EMR tactors and tactors 9-16 are C-series tactors (C-3). Tactor 1 and tactor 9 correspond to the front (belly) position, tactors 5 and 13 to the back with the EMR row below the C-series low. All of the TActions shown were generated in the EAI TAction Creator software tool with a common time base (top scale) in seconds.

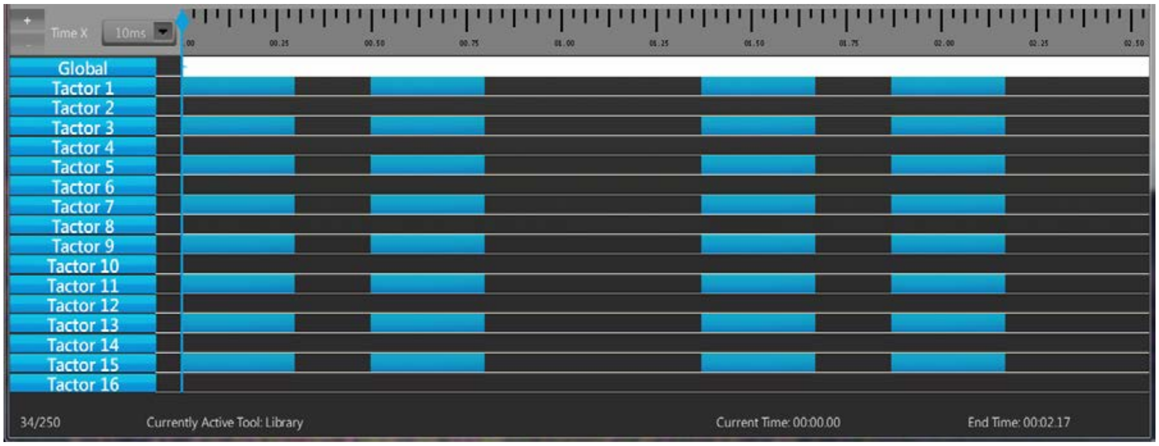
1. Navigation TActions

Waypoint reached (Rally EMR or Rally C-series tactors):



200 ms pulses slightly overlapping with adjacent tactors sites, propagating in a circular pattern CW around the torso. Interim waypoints used only EMR's (tactors 1-8), the final leg waypoint used only the C-series tactors (tactors 9-16).

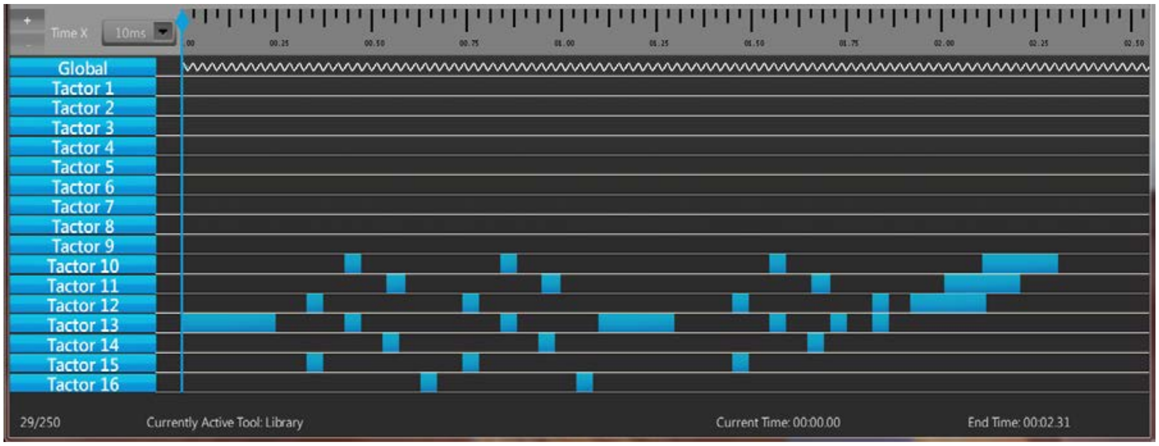
Exclusion Zone (Halt):



300 ms pulses on the front, side and rear tactors, both rows of the belt simultaneously activated (EMR and C-series tactors).

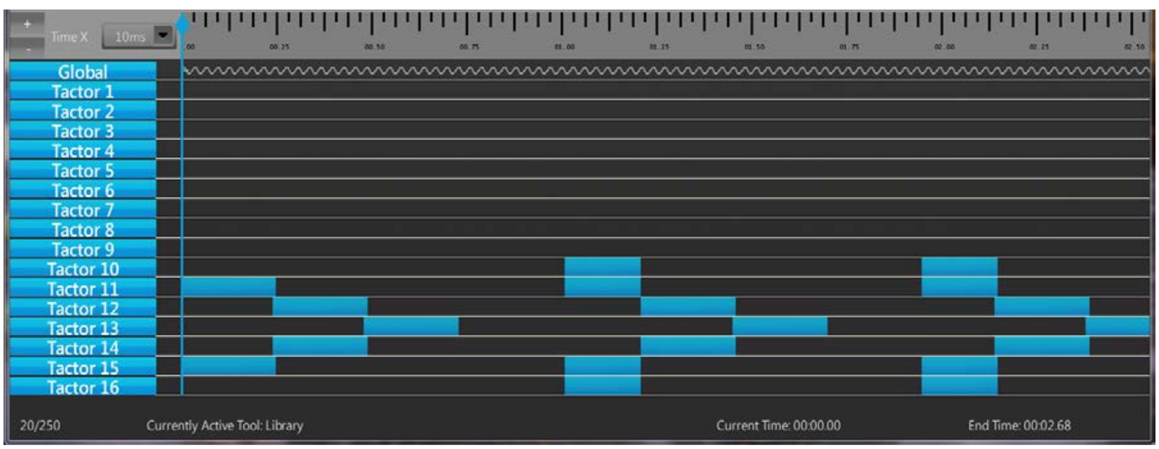
2. Robot Command TActions

Wheels Spinning:



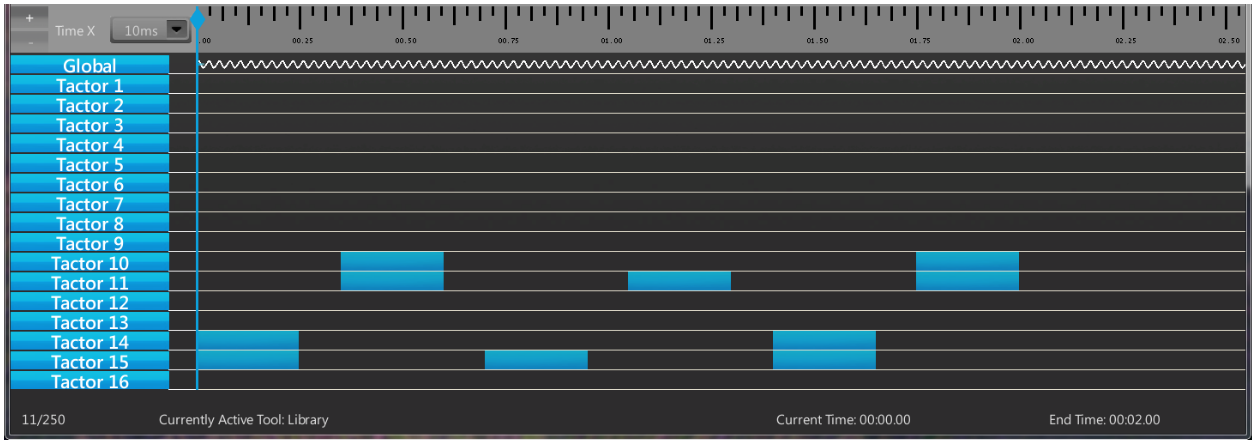
Multiple, 40 to 250 ms pulses ending on the right side.

Battery Low:



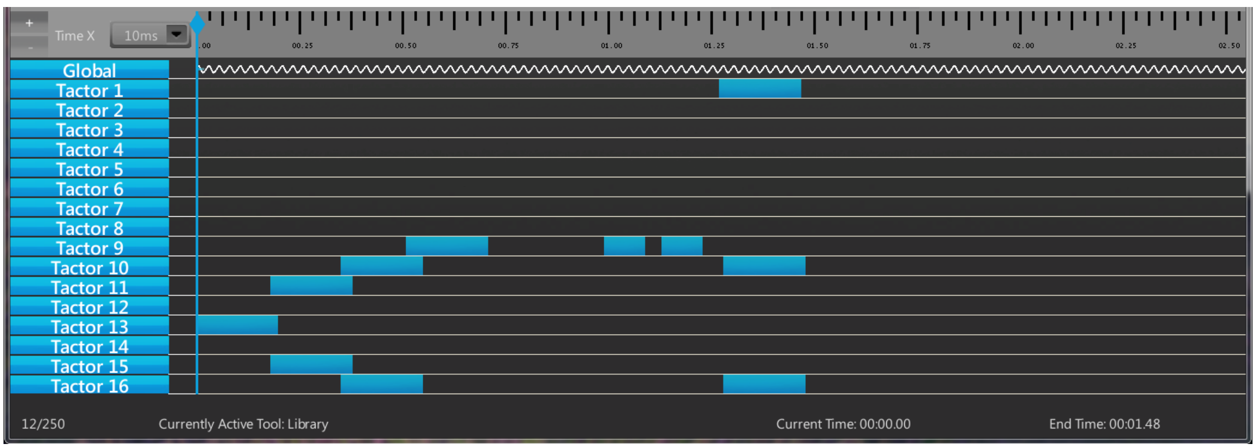
250 ms pulses moving in an “arrow” towards the back (spine).

NBC Detected:



250 ms pulses on diagonal tactors emulating the hand signal for this command.

Possible Target Ahead (Front):



100 to 200 ms pulses moving from the back and ending on a large area on the front (belly) activating one EMR and the row of C-series tactors.

Appendix B. Informed Consent Form

This appendix appears in its original form, without editorial change.

Informed Consent Form

Army Research Laboratory, Human Research & Engineering Directorate, Aberdeen Proving Ground, MD

Title of Project: Soldier-Based Experiment of Dual-Row Tactor Displays During Simultaneous Navigational and Robot-Monitoring Tasks

Project Number: ARL 14-008

Sponsor: Army Research Laboratory

Principal Investigators:

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You are being asked to participate in an investigation of Army equipment concepts. This consent form explains the investigation and your part in it. Please read this form carefully before you decide to take part. You can take as much time as you need. Please ask the staff any questions at any time about anything you do not understand. You are a volunteer. If you join the experiment, you can change your mind later. You can decide not to take part now or you can quit at any time later on.

Purpose of the Experiment

The purpose of this experiment is to evaluate simultaneous presentations of navigation and robot communication/monitoring using tactile patterns comprised of two different types of advanced tactors during operationally relevant scenarios. This dual-row tactile cueing approach has been successfully demonstrated, and was associated with positive regard by Soldiers (Elliott, Mortimer, Cholewiak, Mort, Zets, & Pittman, 2013).

Procedures to be Followed

Prior to beginning of the experiment, you will fill out a demographics questionnaire. You will be briefed on the purpose and procedures of the experiment. During data collection, you will be asked to don a belt containing 16 tactors that, when activated, will provide vibrations like that emitted from a cell phone.

At certain times you will feel a tactile pattern being presented to the belt around your waist. These tactile patterns will represent either a navigational (direction) cue or an alert from the robot that you will be monitoring. Your role is to navigate to various waypoints through the land navigation course and to verbally indicate what pattern you felt whether it be a directional cue or alert cue. Before the testing period, you will be trained on the tactile patterns.

You will participate in a total of two trials consisting of two land navigation courses in this experiment. During each trial you will be you will be moving as if on patrol. On one trial, you will be presented with vibration (tactile) signals and you will be asked to identify each as they occur and utilize the directional cue to navigate to various waypoints through the land navigation course. During some of the legs of this course, you will also be asked to identify various targets. These targets will range from mock IEDs to silhouette targets. You will also perform a similar course with similar task demands, while using only a handheld device.

After each trial, you will be asked to complete a questionnaire. You will be given the opportunity to rest for 30 minutes after each trial. The investigator will record any comments that you may have during this investigation.

Discomforts and Risks

The risks associated with this experiment are considered minimal. The risks that will be encountered during this investigation are typical of the risks encountered by Soldiers performing training and duties pertaining to their military occupational specialty (MOS). The risks include physical exhaustion, muscle strains, cuts, and abrasions. Please inform investigators if you experience any discomfort or problems during the investigation.

Outdoor activities will be suspended during any weather conditions that are inherently dangerous or will cause the investigation trials to be dangerous. To combat the possibility of dehydration or heat related injuries, you are encouraged to take water breaks at least every 30 minutes. Drinking water will be provided.

All other risks anticipated in this Experiment are typical of the everyday risks encountered while working out of doors. There is a risk of tick bites and the potential for Lyme disease. You will be asked to inspect yourself frequently for ticks. Flying insects at the site are also a concern. You are encouraged to use insect repellent, which will be available on site. If you are bitten please notify the principal investigator so that closer visual monitoring of that participant will occur. Various snakes at the site are also a concern. There are also wild animals in the surrounding area. The Soldier will be accompanied by a data collector with Soldier or Combat medical training, who will be in constant touch with the home base. They will be no farther than 300 meters from home base. There will also be a litter placed halfway along the route, with a parked vehicle nearby. In the unlikely event of an injury, a lab phone will be used to call the '911' on-post emergency medical personnel.

Benefits

There are no personal benefits for you for taking part in this experiment. However, your participation will provide valuable information about Soldier performance that will assist in the design of future Army systems.

Duration

It will take approximately 2-3 hours for you to take part in this experiment.

Confidentiality

Your participation in this investigation is confidential. The data will be stored and secured at Aberdeen Proving Ground, in a locked file cabinet. The data, without any identifying information, will be transferred to a password-protected computer for data analysis. After the data is put in the computer file, the paper copies of the data will be shredded. This consent form will be sent to Army Research Laboratory's Institution Review board, where it will be retained for a minimum of three years.

If the results of this experiment are published or presented to anyone, no personally identifiable information will be shared. Publication of the results of this experiment in a journal or technical report, or presentation at a meeting, will not reveal personally identifiable information. The staff will protect you data from disclosure to people not connected with the experiment. However, complete confidentiality cannot be guaranteed because officials of the U. S. Army human Research Protections Office and the Army Research Laboratory's Institutional Review board are permitted by law to inspect the records obtained in this experiment to insure compliance with laws and regulations covering studies using human subjects.

We would like your permission to take pictures/video during the experiment session. The pictures will be printed in technical reports and shown during presentations when we describe the results of the experiment. To protect your identity, we will ask you to remove your name badge and we will pixelate the image to obscure your face. You can still be in the experiment if you prefer not to be photographed/videotaped. Please indicate below if you will agree to allow us to take pictures of you.

I give consent to be photographed/video during this experiment: ___Yes ___No
please initial:____

Contact Information for Additional Questions

You have the right to obtain answers to any questions you might have about this effort both while you take part in the experiment and after you leave the Experiment site. Please contact anyone listed at the top of the first page of this consent form for more information about this experiment. You may also contact the chairperson of the human Research & Engineering directorate, Institution Review board, at (410) 278-5992 with questions, complaints, or concerns about this effort, or if you feel this experiment has harmed you. The chairperson can also answer questions about your rights as a participant in this effort. You may also call the chairperson’s number if you cannot reach the investigators or wish to talk to someone else.

Voluntary Participation

Your decision to be in this investigation is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this experiment will involve no penalty or loss of benefits you would receive by staying in it.

Military personnel cannot be punished under the Uniform code of Military Justice for choosing not to take part in or withdrawing from this experiment, and cannot receive administrative sanctions for choosing not to participate.

Civilian employees or contractors cannot receive administrative sanctions for choosing not to participate in or withdrawing from this experiment.

You must be 18 years of age or older to take part in this investigation. If you agree to take part in this effort based on the information outlined above, please sign your name and the date below.

You will be given a copy of this consent form for your records.

Do not sign after the expiration date of

____ ___________

Participant Signature date

____ _____________

Person Obtaining consent date

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Appendix C. Demographic Questionnaire

This appendix appears in its original form, without editorial change.

Demographics Questionnaire

Date: ________________Participant ID (ROSTER): _________

1. General Information

a. Age (yrs): _____ b. Gender: M F c. Handedness: L R

d. Height (in): ______ e. Weight (lb) __________

f. Do you have corrected vision (Circle one)? None Glasses Contact Lenses

g. Do you have any hearing loss or other impairments? If so, please explain.

____

____

h. Do you currently have any skin sensitivities on your torso (chest, waist) that might be irritated by wearing a haptic belt (for example, poison ivy, insect bites, rash, etc.)?

____

____

i. On a scale from 1 to 5, how ticklish are you? (chest/waist area)

1 = Not at all_________2____________3___________4__________5 = Very ticklish

2. Military Experience

a. How many years have you been in the military? ________ Current rank ____________

b. What is your MOS? ________________

c. Please list all combat deployments (Iraq, Afghanistan, etc.) and the length (Years / Months) of each.

Location Time

____________________________________ ________________________

____________________________________ ________________________

d. Do you have operational experience in woodland terrain? ___Yes (#years_____) ___No

e. Do you have any experience with reconnaissance (e.g., searching for targets)? ____Yes ___No

If yes, please explain (dismounted infantry) or (mounted-vehicle)

Medical Status Form

Experiment participant: Please answer all questions honestly and completely. It will not be entered into your official health records and will be treated confidentially.

Roster Number: ____________ Date: ________________________________

1. Do you have any physical injury at the present time?

Yes ______ No ______

If yes, please describe.____

2. Have you had any surgery in the last two months?

Yes ______ No ______

If yes, please describe.____

3. Are you presently on a profile of any type? Yes ______ No ______

If yes, please describe your current limitations.

____

4. If the APFT (Army Physical Fitness Test) were held today, could you obtain a passing score on it? Yes ______ No ______

Appendix D. NASA TLX

This appendix appears in its original form, without editorial change.

NASA TLX   Definition of Task Demand Factor

Mental demand

How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical demand

How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal demand

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance

How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Frustration level

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Effort

How hard did you have to work (mentally and physically) to accomplish your level of performance?

NASA-TLX Mental Workload Rating Scale

Please place an "X" along each scale at the point that best indicates your experience with the robot controller you just used.

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low High

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

Performance: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low High

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low High

Frustration: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

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Appendix E. Comments

This appendix appears in its original form, without editorial change.

Comments:

How would you recommend using the tactile belt (which people, what situations)

I think it would be good to give to leaders and it could be used to communicate on a patrol when low noise is a priority. Also at night or low light conditions
I would recommend this to the Platoon leader and the point man moving through the wood line.
Covert noise and light discipline
You can use it in any type of situation
Point man while navigating
Not often, especially not a team leader or up
Point man, TL, SL, During patrols, missions, movements
Anyone who has to pay attention to multiple things while moving from point A to point B. Like Soldiers in a combat zone. Or patrolling through a forest.
I highly recommend using the tactile belt by all positions of a squad
Recommend the point man using the tactile belt while patrolling in the woods through the night
Everyone should have one. I can't think of many situations it couldn't be used.
Would be beneficial for point man, team leader, and squad leader
For situations of radio silence and when there are stealth operations
I believe this belt in the future could be implemented to the everyday Soldier in the field on missions involving any form of navigation if noise volume could be reduced and proper train up (more training) were introduced.
I would use it on the point man and platoon leader during patrols.
Team leaders should use the belt on patrols to be aware and notify his team of the situation during the patrol
In situations of low visibility and when you need to move a squad member in a more tactical position
Infiltration, recon
point man in any navigational operations
everyone all situations
Leaders and point man so they can convey the message

Time of day would not matter, it would be effective in day and night. I think infantry would benefit from the tactile belt the most, also scouts. I don't think it would benefit mounted all that much because they don't dismount that much. .
Every condition
At night where silence is desired, or when there is an issue with hand signals or word of mouth
On patrols for infantryman but I feel it may need to be more silent. It would also be good to find your natural walking shift in the woods for land nav.
Combat MOSs or units making movements land nav, movements
At night when movement on the enemy.
Point man on patrols and PLS, snipers or SKTS.
Any situation during land navigation would benefit from the tactile belt.
Mainly point man and id use it day or night in any situation.
Ranger, Infantry, Cav Scout, Sniper, Combat engineers, and any combat MOS with major mission on foot or vehicle.
When going somewhere we have not been before everyone.
I feel all should use it just in case an ambush may occur and Soldiers get separated - they can each end up at same point.
For infantry in an unfamiliar area
Everyone could use this system, when a squad is doing recon or needs to be silent

What would be some useful commands for the Tactile belt system?

Any of the basic commands would work (halt, file, wedge, etc.)
Get down, get in a file or a wedge formation
Halt, get down, formations
Proceed after a waypoint
It could be used to change formations during low visibility
None cus that takes focus off the fight to multitask
Halt, get down, where to scan
Get down, halt, move out, enemy spotted, IED

Contact left, contact right, movement formations
Robot contacted enemy, robot contacted NBC, robot contacted final waypoint
Any hand signals would be great.
Pull security or line formation and column formation
The idea of Soldier to Soldier application would be interesting but first how would you effectively implement a control system. Hand signals are as effective unless some kind of control system in even brought up.
When a potential threat could possibly occur and your trying to remain silent.,
To be on alert for a hostile situation or to get the attention of another Soldier.
I don't know
hold position, move out
would not want to
point man sees threat
Possible target direction, move out
We are under fire. Type of fire indirect, or direct, alert other teams of a casualty
Halt, move forward
1. Enemy at (grid coordinates), 2. Rally point, Fobs, friendlies at (grid)
na
Obstacles, enemy units, short halts
Halt, Danger area
Shift and lift fires and other time-oriented events
To use the belt instead of passing hand signals back while during movement
Give the location of the robot to both Soldiers and each other.
Low firm vibrations.
I like the robot idea (send it out there in front of us)
When one may need help, may have somehow got off track, may need medical assistance, may have seen IED or noticed something
For distance between Soldiers, warnings other Soldiers might see.
Ammo checks, making sure a person is ok.

What are potential advantages of the Tactile/Visual system?

It has the ability to send signals quickly and silently. You can do land navigation with no thought involved.
A faster way to get to one point to another and it's a lot quieter than a radio.
Tactile-very easy to move to points and scan at the same time, commands were easy to recognize
The belt is more tactical and made for you to move faster
Tactile belt allows you to navigate while continually scanning sectors
Move faster at night
Getting you to your position with ease
With the visual display you can easily see the exact point and how far it is so it was an advantage to know where its at. The tactile belt system was a major advantage to get me to my point as fast as I could move and still keep my eyes scanning and keep me aware of my surroundings.
Faster way to get from one point to another without stopping to check a GPS.
You find your way easier to your waypoint and it keeps you out of danger.
Being able to stay aware of your surroundings.
Being able to make long movements without having to check map as often
radio silence and having the advantage of seeing on a map display where you are
The belt and vibrations are very effective when a baseline confidence in the equipment is established. The belt alone allows for a higher level of alertness and more focus on the surroundings, with the visual display you can effectively get out of marked mine fields more efficiently.
It is way more effective and faster than conventional land nav. It allows the Soldiers to stay more effective towards threats.
The tactile belt provides communication with minimal noise and the visual display provides a very quiet and effective way of moving in a hostile environment.
Its faster and less time consuming and easier than a compass
hands free, easier and simpler to use
keeps Soldiers from having to work hard at land navigation
no visual display
quick easy deployment of Soldiers to a point
Faster at finding points than map and compass tells you the direction and alerts you to let you know it you are in danger zones.
Noise, silence

When silence is desired
It can improve speed to moving to a specific point.
Belt had great potential and doesn't really need improvement. Visual needs a way to notify when going off course and make distance in meters not feet, also increase refresh rate. Also would help to show terrain.,
na
Less movement time, better advantages at night
Using the belt required less screen use. This prevented my eyes having to readjust to the night.
For visual display you can see the accurate location and distance of each waypoint.
Land nav moveability, and location on the battlefield
Making land nav easier for everyone
It takes a lot less time, you can pay more attention to your surroundings and be more aware of your surroundings
Save time, allows you to focus on surroundings and not your map or pace count.
Better way to stay silent when it is a must.

What are main concerns that need improvement?

Durability is one issue. It would also need to be somewhat quieter. I think it would be good to send signals on a patrol where noise and light discipline is an issue but once you're shooting and moving fast. I think you would tune out the signals.
Battery life.
Lag, if possible, on the visual. Different color for contours or triangle representing you.
none
The visual should not beep it will give away your location
Easy system, Infantry ain't smart just keep it simple. Make the display screen red light and feet to meters.
Noise, compatibility with the environment, not breaking easily (durable), weatherproof.
The sound it makes when it vibrates and a way to silence the audible noise is the only thing so far holding it back.
A dimmer display so the visual display is not as bright.
The tactile belt needs a little bit more silent. The GPS screen should be smaller so we can leave the screen down and find our way to our waypoint easier.
Make it more quiet. That's all.
a little more rugged.

Having a better way of securing the belt. Possibly having built into a shirt.
Reduced volume, greater ability to feel vibrations, at one point I did not feel a waypoint entirely, and was only made aware by direction change. These things, along with a possible implementation into IOTV or possibly not, such a delicate electronics system and make it more rugged. I feel this system will definitely benefit Soldiers in the field.
Battery life and durability could be an issue when moving through very rough terrain.
The Soldier needs to be trained very well on the equipment and needs to be more quiet when alerting the Soldiers.
none
visual should be converted to meters
Change distance to meters, need to repeat alerts in case missed initially.
no visual display
Breathabililty (of fabric), durability, availability to other Soldiers
The belt has a constant buzz makes you go numb. It would be better if it would let you know what direction to travel in and stop buzzing and when you need to turn it buzzes in that direction until you are facing in that direction and then stop, until you have to buzz again. The alerts on the belts are kind of the same. So if you are running or have an adrenaline rush you could mistake it for another alert.
Durability, noise, price, placement
The base system needs a better rig to withstand combat
It needs to be more quiet.
The Belt's potential is maximizing speed of movements and notifying Soldier of surroundings- visual display is more needing of attention but gives a visual or picture of what's around you.
na
Velcro on belt is weak. Having it as a belt style with more secure latches would be my only critique.
Sound and light.
The belt some vibrations were too loud and the screen light too bright.
How it will fix to our gear / weight (keep adding little by little will make a lot.
The loudness. Everything else amazing.
Accuracy of the map.
Sat signal.
distance in meters, kills night vision.

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List of Symbols, Abbreviations, and Acronyms

ANOVA	analysis of variance
CI	confidence interval
EAI	Engineering Acoustics, Inc.
FB	feedback
GLM	general linear model
IMU	inertial measurement unit
MOLLE	modular lightweight load-carrying equipment
NASA TLX	National Air and Space Administration Task Load Index
NBC	nuclear, biological, chemical
SD	standard deviation

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